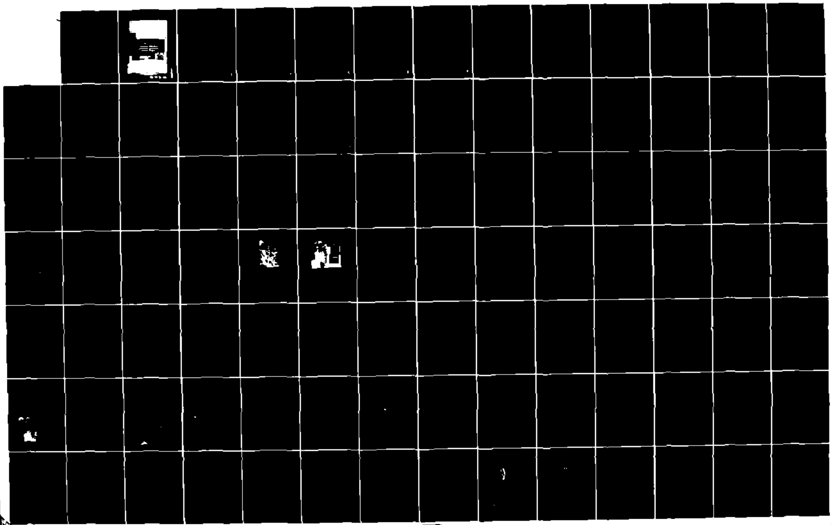
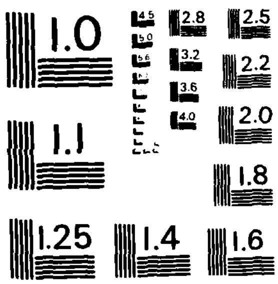
AD-A138 965 NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE(U) ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT NEUILLY.. R CARRE ET AL. 1/3

UNCLASSIFIED DEC 83 AGARD-AG-277(E) F/G 6/5 NL






MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AGARD-AG-277(E)

AGARD-AG-277 (E)

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARDograph No.277 (E)

# NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE

by

R.Carré

with the collaboration of

| | |
|---|---|
| R.Amoretti | G.Leguay |
| A.Coignard | P.J.Metges |
| J.Colin | M.Puech |
| A.Didier | C.Risadeau-Dumas |
| J.Droniou | A.Scano |
| J.F.Gaillard | A.Seigneuric |
| Ch.Hiltenbrand | J.Timbal |
| H.Ille | B.Vettes |
| Ph.Lantrade | H.Vieillefond |


Voir l'AGARDographie No.277 (Fr.) pour le texte français

**This AGARDograph was prepared at the request of the Aerospace Medical Panel of AGARD.**

## THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Programme and the Aerospace Applications Studies Programme. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced directly from material supplied by AGARD or the authors.

Published December 1983



ISBN 92-835-1464-5

*Printed by Specialised Printing Services Limited*
*40 Chigwell Lane, Loughton, Essex IG10 3TZ*

## INTRODUCTION

Non-invasive cardiological methods are useful in the expert medical examination of flying personnel since, because they are non-invasive, they are readily accepted by the subjects. They provide easily reproducible records which can be used to compare the findings of one examination with those of another. These records can be included in a case record and constitute medico-legal evidence.

These examinations can be divided into three categories:

(1) The standard electrocardiogram and cardiac X-ray are obligatory additions to expert clinical examination, which forms the basis of cardiological assessment.

(2) In some special cases, the expert may employ complementary examinations: exercise test with electrocardiographic recording, Holter 24-hour electrocardiographic monitoring, echocardiography with its various modalities – TM, two-dimensional, ultra sound, isotopic exploration.

(3) The special cardiological tests are useful either as a complementary examination in the expert medical examination or else for the purpose of physiological research in aeronautical or space medicine. These include: Rheocardiography with determination of the intervals of systolic time, balistocardiography, tilt table, LBNP-test and centrifuge.

With the introduction of new fighter aircraft with more sudden, severe and prolonged accelerations, these cardiological methods will probably become more important.

The aim of some of these tests will be to establish more accurately the organic or functional integrity of the cardiovascular system. Other tests, especially those known as "special tests" will be used as selection tests intended to pick out the candidates best able to tolerate the most extreme accelerations.

Médecin Chef des Services CARRE

## LIST OF AUTHORS

R.Carré
A.Didier
H.Ille
M.Puech
R.Amoretti
Centre Principal d'Expertise Médicale du Personnel Navigant de l'Aéronautique
26, boulevard Victor
75996 Paris Armées
France

P.J.Metges
Hôpital d'Instruction des Armées Bégin
94160 Saint Mandé
France

G.Leguay
A.Seigneuric
Hôpital d'Instruction des Armées Dominique Larrey
78013 Versailles
France

J.Colin
Centre des Recherches du Service Santé des Armées
1 bis, rue Lieutenant Raoul Batany
92140 Clamart
France

A.Coignard
J.Droniou
J.F.Gaillard
Ch.Hiltenbrand
Ph.Lantrade
C.Ribadeau-Dumas
Hôpital d'Instruction des Armées du Val de Grace
74, boulevard de Port-Royal
75230 Paris Cedex 05
France

A.Scano
Postgraduate School of Aerospace Medicine
Rome University
Italy

J.Timbal
Centre d'Etudes et de Recherches en Médecine Aérospatiale
26, boulevard Victor
75996 Paris Armées
France

B.Vettes
H.Vieillefond
Laboratoire de Médecine Aérospatiale
91220 Brétigny sur Orge
France

## CONTENTS

# CHAPTER 1

## MAIN ELECTROCARDIOGRAPHIC ABNORMALITIES IN THE MEDICAL EXAMINATION OF FLYING PERSONNEL

by R. Carré*, A. Didier**, and H. Ille**

The flying of very high performance aircraft such as the Mirage 2000 or 4000, demands that flying personnel be selected to ensure maximum flight safety. During such flights, the cardiovascular system is the physiological system exposed to the greatest stress.

Military regulations concerning the medical suitability of flying personnel require total organic and functional integrity of the circulatory system.

An electrocardiogram with 6 peripheral and precordial leads is performed at each admission or review check up of the flying personnel.

Unsuitability of flying personnel is readily established if any of the signs listed below are present:

- arrhythmias: flutter, atrial fibrillation, obvious conduction disorders;
- complete right bundle branch block or complete left bundle branch block;
- sequellae of myocardial infarctus, some of which the subject may be aware of, but others which may not be apparent to the pilots themselves. Over a 10-year period, we detected eight cases of myocardial infarctus which had passed unnoticed and were discovered during routine review examinations. In some difficult cases a vectocardiogram may be useful.

However, some electrocardiographic recordings may be indecisive and we envisage investigation of the following features:

1) Certain arrhythmias
2) Partial right bundle branch blocks
3) Left axis deviations and their relationship with the notion of left anterior hemiblock
4) The Wolff-Parkinson-White syndrome
5) Atypical ventricular repolarisation

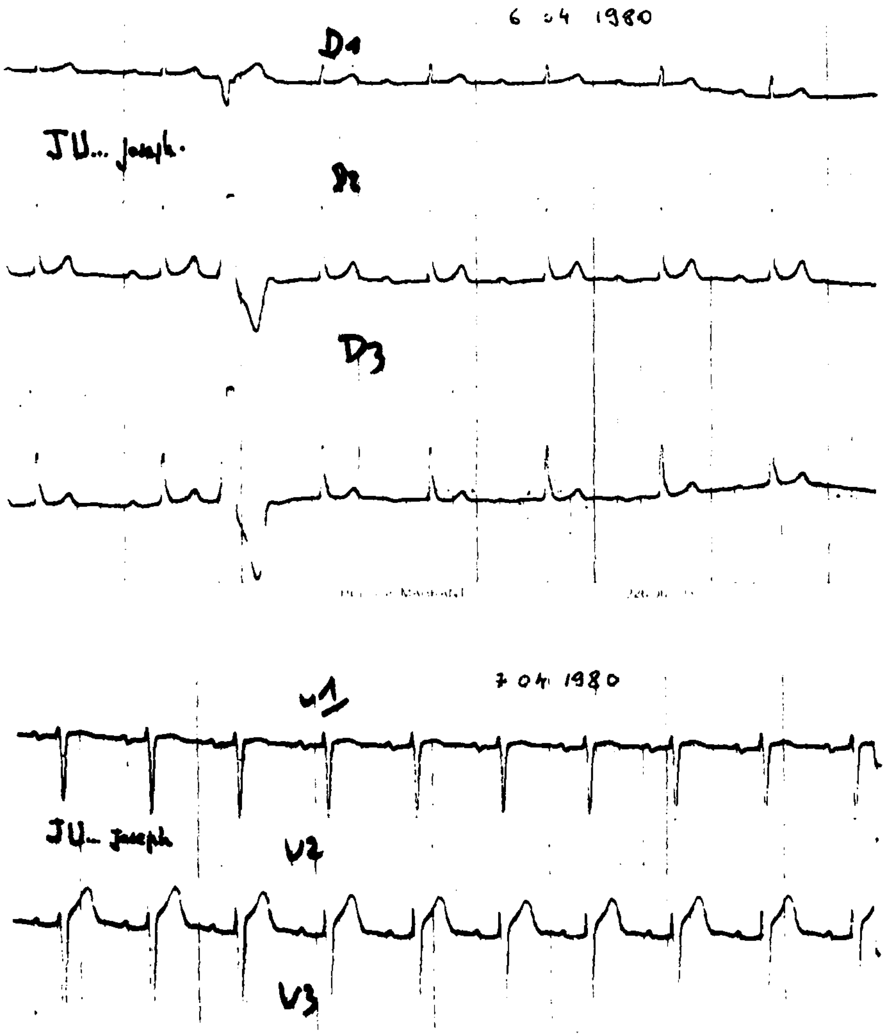
### I - ARRHYTHMIAS

Excitability disturbances are frequent. Atrial, nodal and ventricular extrasystoles are routinely detected; but it is difficult to establish an acceptable threshold. Holter-monitoring involving 24-hour electrocardiographic recording, has demonstrated the frequency of such disturbances in the asymptomatic subject and it is difficult to establish criteria of normality in this area. Various studies (3) (5) (8) have established certain features:

- over 24 hours, nearly 50% of subjects present ventricular extrasystoles; ventricular extrasystoles are common in the elderly but rare in young subjects; when they do occur it is at a frequency of less than one per minute and isolated rather than occurring as doublets or salvos.
- atrial extrasystoles are commonplace in the elderly and rare in young subjects, unlike nocturnal sinus pauses which are frequent in young subjects without apparent heart disease; these are always nocturnal and result from excessive vagal tone (13) (6).

Many rhythm disturbances disappear during certain forced tests (exercise test) and do not indicate any lack of fitness but when these extrasystoles occur, either during or following an effort test, or during aeronautical force tests (centrifuge, orthostatic test, Lower Body Negative Pressure test), they do cast doubt on suitability for flying.

* Médecin Chef des Services
** Médecins en Chef
Centre Principal d'Expertise Medicale du Personnel Navigant de l'Aeronautique
26 Bd. Victor - 75996 Paris Armées France.

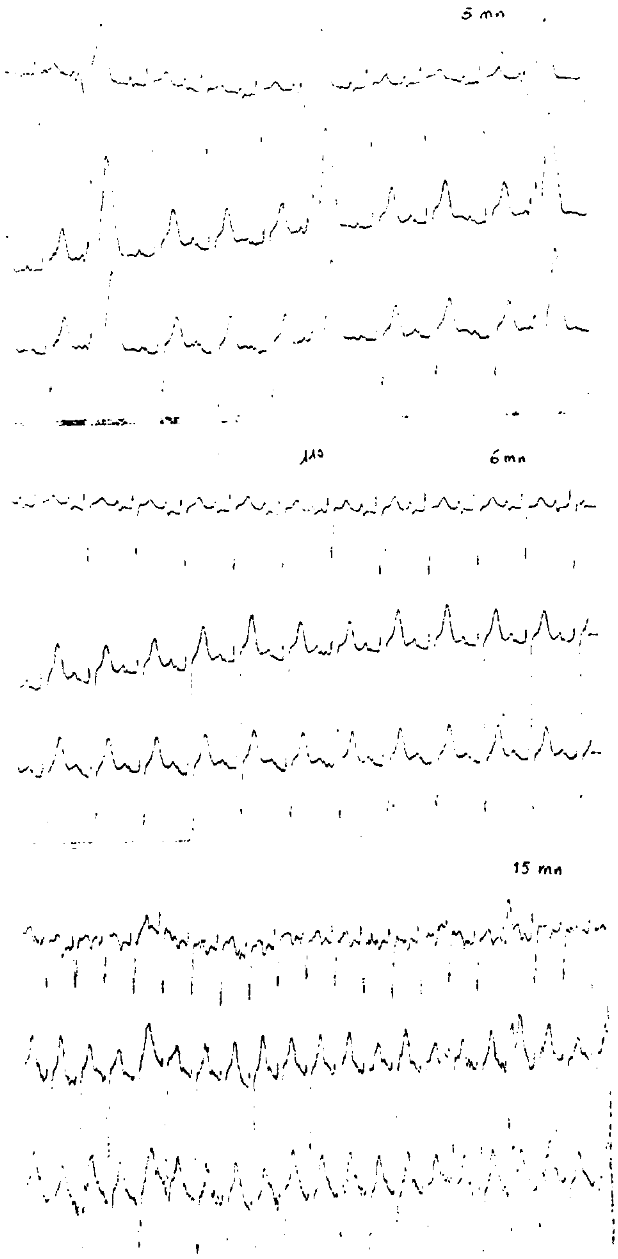



Photograph 1  JU ... Joseph 24 years W.70 kg H.1.80 m
Fluctuations of conduction and excitability disturbances

Atrioventricular conduction disorders obviously disbar the subject from any post involving flying. However, lengthening of the PR interval is more debatable:

- first we have to define normality, on the basis of histograms obtained from 200 patients, the PR interval can be said to be prolonged if it exceeds 24/100ths of a second;
- then the significance of this must be determined: is this of vagal origin (constitutional or acquired), or is it some impairment of specific conduction tissue which could deteriorate further?

Since the introduction of endocavitary recording of the potentials in the bundle of His, it has become clear that the significance of impairment of atrioventricular conduction may vary: a supra-His block is generally less serious than an infra-His block. The problem, therefore, is to establish whether a first or even second degree disorder of atrioventricular conduction is a benign abnormality or not, and how to determine this by means of a simple, non-invasive method. The frequency of cardiac conduction abnormality in the athletic subject (19) is established. This is explained on the basis of a functional disorder of vagal origin, like the bradycardia of the athletic heart.




Photograph 1 - JU ... Joseph 24 years W.70 kg H.1.80 m
exercise ECG - disappearance of excitability disorders
with accelerating heart rate

The pneumogastric nerve or vagus which constitutes the Xth cranial pair is a sensory-motor nerve with a large territory including the thoracic vicera and, in particular, the heart. The fibres of the right pneumogastic destined for the heart supply the posterior part of the atrium and, in particular, Keith's bundle; the left vagal fibres are closely related with the Aschoff-Tawara node and less closely with the ventricles.

Stimulation of the vagus slows the heart rate (negative chronotropic effect); if the stimulation is intense, arrest occurs in diastole, which always terminates in escape triggered by the pacemaking activity of the node. Stimulation of the pneumogastric nerve depresses atrioventricular conduction (negative dromotropic effect) . This is reflected in the ECG by a lengthening of the RP interval and even by second degree atrio-ventricular block (AVB). Recordings of the electrical activity of the bundle of His situates the disorder as an impairment of atrio-his conduction (lengthened AH segment). However, stimulation of the left pneumogastric more easily gives rise to second or even third degree AVB.

Two simple tests establish the involvement of the vagus:

- ocular compression during electrocardiographic monitoring, investigation of the oculocardiac reflex (OCR)
- the atropine (a natural parasympatholytic) test

Study of the oculocardiac reflex: compression of the eyeballs for 15 seconds produces slowing of the heart rate in most subjects. The severity of the slowing varies and may result in cardiac arrest in diastole.

The test is positive if it results in :

- either a cardiac pause of at least 5 seconds
- or clinical signs (syncopy) or (presyncopic signs).

The atropine test consists of taking an electrocardiographic recording before and 45 minutes after intramuscular injection of 1.5 mg of atropine. The test is positive if it produces a clear shortening of the PR interval.

However, some reservations have been expressed with respect to the value of this test. The test may improve A-V conduction even in the presence of organic disorder. However, functional disorder is more probable if the disorder varies with time, if it is not accompanied by any organic lesion detectable by the clinical examination and the usual complementary examinations (ECG, X-ray) and if the subject demonstrates good tolerance to aerodynamic stress tests (hypoxia, depression, acceleration). However, this does not entirely rule out the possibility of a congenital weakness of the conducting tissue likely to deteriorate with time. Regular check ups are necessary and the regulations provide for an annual check up for all flying personnel and a six-monthly check up for pilots. In some doubtful cases, only recording the electrical activity in the bundle of His is really decisive.

When vagal involvement is apparent, it may appear either as a mechanism of adapting to repeated stress, similar to that of the athletic heart, or else as a dysfunction of these same sympathetic adaptation mechanisms. In the latter case, vagal tone is responsible for malaise and even loss of consciousness and is a negative factor which may result in occupational unsuitability.

## II - PARTIAL RIGHT BUNDLE BRANCH BLOCK

The most commonly encountered aspects of partial right bundle blocks are, in the opinion of the authors, not incompatible with aviation if the total duration of the QRS complex does not exceed 12/100ths of a second, if the rSr' VI block remains unchanged or disappears during the Flack test or endurance test at 40 mm Hg.

A statistical study carried out at the Centre Principal d'Expertise Médicale du Personnel Navigant at Paris has established that these features of partial right bundle block were present in 12% of candidates at admission and that this percentage was higher the younger these subjects. It can therefore be advanced that frequently these features of partial right bundle branch block, which may disappear during Flack rotation, may be merely a physiological aspect of the youthful electrocardiogram. It would therefore be an error to eliminate automatically all subjects presenting such features, especially since multiple simultaneous recordings from several leads terd to include as partial right bundle branch block similar morphological images, some of which present an r' peak which obviously does not correspond with delayed contraction of the right heart.

## III - LEFT QRS AXIS DEVIATION

Determination of the mean axis of the QRS complex in the frontal plan is a fundamental element of the analysis of an electrocardiogram recorded in the usual way. This axis is normal for adult subjects if it lies between -30° and + 110° (16).

Apart from any pathological cause, the electrical axis of the heart varies within this range depending on its anatomical position in the thorax. Although there is no constant correspondance, a horizontal position of the heart is often associated with a shift of the electrical axis towards the left, whereas right deviation is often found with the heart vertical.

A clear deviation to the left of the QRS axis in excess of -30° is often indicative of a pathological condition: it is present in some congenital heart diseases and is suggestive in particular of left ventricular hypertrophy. It is generally admitted, after GRANT (10), that in isolation such a deviation has a negative significance; morbidity and mortality due to cardiovascular disease, in particular to coronary artery disease, is higher amongst subjects with this abnormality than amongst the general population.

The anatomo-clinical observation of BAHL et al (1) support this: 344 of the 453 subjects investigated, all of whom presented left deviation of the QRS axis, were studied in an epidemiological study involving 4678 subjects aged over 20 years. In 41% of the subjects with this abnormality, it was an isolated feature. The subjects were followed up over a 4-year period and cardiovascular morbidity and mortality were no different from those of the rest of the population.

A new physio-pathological concept has emerged from the studies of GRANT in 1956 (10), of LENEGRE in 1958 (14), of PRYOR and BLOUNT in 1966 (17) and especially of ROSENBAUM in 1968 (23) . This is the concept of hemiblocks of the left branch of the bundle of His division which rapidly established itself as a source of major QRS axis deviations.

## CURRENT CONCEPTS OF VENTRICULAR ACTIVATION

The bundle of His divides into two branches, right and left, which propagate the stimulus received from the Aschoff Tawara node to the ventricles.

Diagram of the
Division of the bundle of His
and its branches

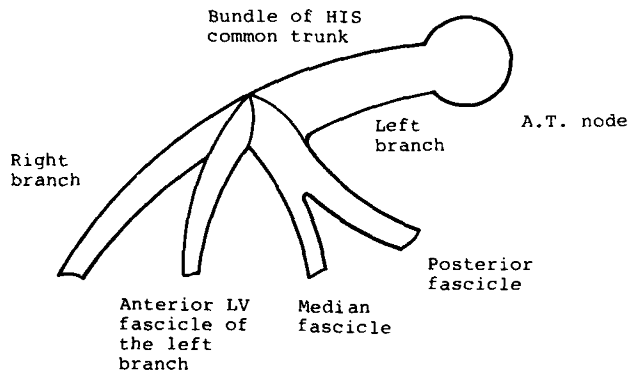
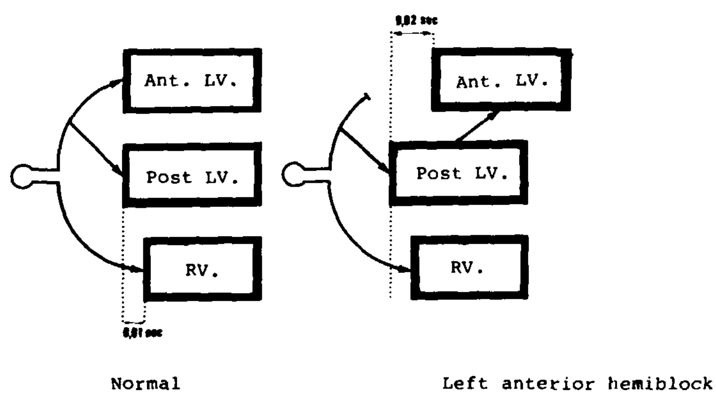



Diagram of
Ventricular activation




(after Fernandez)

Whereas the right division is single until its terminal arborization, the left division divides into several secondary fascicles. There is a range of anatomical variations which are debatable but on the functioning level, the sequence of events follows that of ROSENBAUM's original concept: an anterior and superior fascicle activates the corresponding areas of the left ventricular myocardium, the rest of the ventricles being activated by an inferior, posterior fascicle.

The left branch hemiblocks are therefore defined as systematic impairment of intraventricular conduction involving one of the fascicles of the division of this branch. We will not discuss posterior left hemiblock further, this is much less frequent in isolation than anterior block and we found no examples of it.

Left anterior hemiblock produces delayed activation of the anterior upper half of the left ventricle. The electrocardiographic repercussions have now been clearly established (FERNANDEZ (9):

- the initial vector, reflecting septal activation, loses one of its left components and is shifted downwards, rightwards and forwards. The extent of this shift depends on the extent of the lesion, as the vectocardiographic studies of CLEMENTY, BROUSTET et al (4) have shown;
- the delay in activation of the upper anterior half of the left ventricle results in a leftward deviation of the axis of the terminal vectors;
- over all, the main sign of left anterior hemiblock is left axis deviation of the electrical axis of the maximum vector.

The table below shows electrocardiographic criteria of this hemiblock.

| Sinus Rhythm | |
|---|---|
| Duration of QRS | Normal or increased up to 12/100th of a second |
| QRS Axis | between - 30° and - 90° |
| First vectors | q1, r2, r3 |
| Last vectors | shifted leftwards |
| Lewis' index | may exceed + 17 |
| V4 - V5 - V6 | R/s pattern |
| V1 - V2 | Variable, sometimes r S r' |
| Repolarisation | Normal or secondary disturbances |
| Intrinsic AVL deflexion | Over 5/100th of a second |

Before considering the clinical significance of these electrical features, we should eliminate some possibilities.

Differential diagnosis:

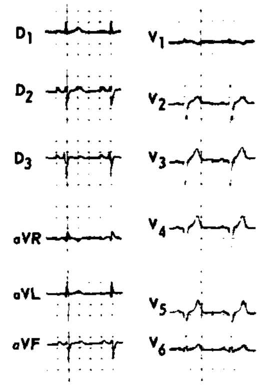
The so-called positional left deviation of the QRS axis does not normally exceed -30°.

Left ventricular hypertrophy is recognised from the clinical, etiological, and radiological context, and from abnormalities of the ECG recordings. Some authors hold that clear left axis deviation is in cases of left ventricular hypertrophy, a sign of true hemiblock.

The Wolff-Parkinson-White syndrome, type B, is accompanied by a leftward shift of the QRS axis.

The relationship between left anterior hemiblock and myocardial infarctus are more complex : (FERNANDE Z (9)).

- hemiblock may resemble antero-septal necrosis in the appearance of the QS segment and in a reduction of the r waves from V1 to V3,
- hemiblock may be associated with the infarctus,
- hemiblock may mask necrosis (antero-septal or diaphragmatic).




CASE N° 27
SOU ..., 21 years, 1.76 m, 66 kg
Clinical signs = N.A.D.

Typical ECG record
in left anterior hemiblock

The diagnosis can be corrected by recording with electrodes in a low position or better still, using a vectocardiograph.

## CLINICAL SIGNIFICANCE OF LEFT ANTERIOR HEMIBLOCKS

The main etiologies of this conduction disorder are summarised in the table below:

| | |
|---|---|
| Congenital heart diseases | Ventricular septal defect<br>Atrioventricular canal<br>Tricuspid atresia<br>Single ventricle |
| Acquired heart disease | Aortic valve disease<br>Hypertension<br>Obstructive myocardiopathy<br>Alcoholic myocardiopathy<br>Amylosis, haemochromatosis<br>Friedreich disease<br>Myotonia and muscular dystrophies<br>Chagas-disease<br>Coronary artery disease<br>Primitive disorders of the conduction pathways |
| Functional causes | Hyperkalaemia<br>Digitalis overdose |

According to FERNANDEZ, in 25 % of cases, left anterior hemiblock appears to be ideopathic in healthy subjects who appear normal when subjected to clinical examination.

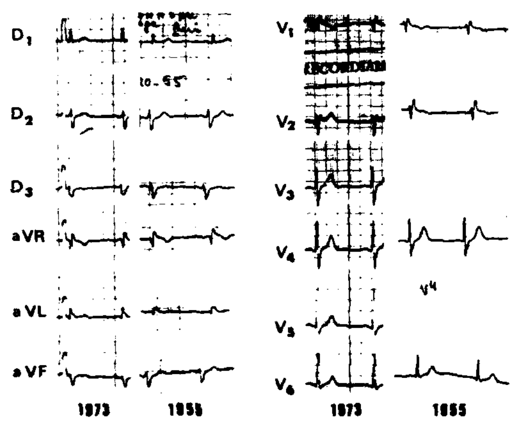
When the various etiologies have been eliminated, the condition must be classified as one of the following:

1 - silent coronary artery disease
2 - a degenerative condition, such as LENEGRE or LEV's disease
3 - such as to be compatible with a healthy state.

60 cases of QRS axis deviation are reported (7). They can be divided into two classes:

1 - Cases in which a pathological factor emerges as the probable or possible cause of left axis deviation. Some of these pathological factors are obvious, such as overweight, moderate hypertension, diabetes or mixed hyperlipidaemia. In other cases, none of these factors are detected, but the QRS axis shifts over the years, possibly indicating the development of a chronic disease process.

The association of left QRS axis deviation with a complete right bundle branch block have been included in this group. Theoretically, this combination implies that conduction into the ventricles occurs only through the left posterior division. Prognosis for this type of fascicular block is subject to discussion.




BIG ... Pierre, 51 years, 1.74 m, 70 kg.
RBBB with QRS = 10 - 12/100 sec. and LAH
UNCHANGED SINCE 1955

According to FERNANDEZ (9) and following LENEGRE and BLONDEAU (2), development towards complete atrioventricular block takes place in only about 50% of cases, the proportion depending on the etiology, almost 100% of idiopathic cases, 33% of coronary artery failure cases and 25% of myocardiopathy cases.

Unlike other authors (GUEROT, COSTE and TRICOT (11) after SCANLON, PRYOR and BLOUNT (22) think that development into complete atrioventricular blocks occurs in only 10 to 15% of cases.

Findings of investigations of recordings of the action potentials in the bundle of His by various authors are also contradictory:

- NARULA and SAMET (15) found abnormal intra-His conduction (in the only remaining His-ventricular pathway) in 49 out of 68 cases of complete right bundle block with clear left axis deviation;

- RANGANATHAN (20) found the same situation in 5 out of 10 cases;

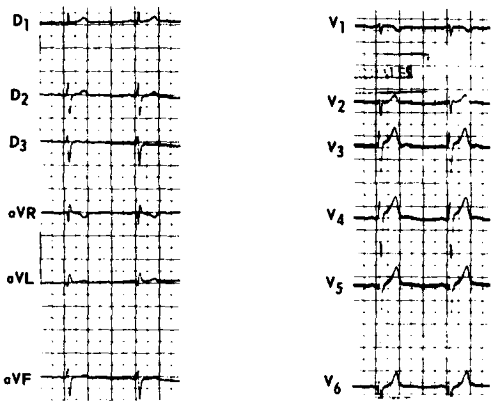
- GUEROT, COSTE, VALERE, MOTTE and TRICOT (11) found, however, normal His-ventricular conduction in most cases.

We have noted that in this type of association, left side delay is generally of the minor type described by Fernandez.

D 1 = qRs wide,
D 3 = rSr' wide

as compared with right block "mascarading as left bundle branch block" reflecting considerable delay on the left side with the following features:

D 1 : qR
D 3 : rS




CASE N° 49
VIL ... Georges, 28 years, 1.62 m, 56 kg
Clinical signs = N.A.D.

TYPICAL ECG RECORDING OF A "LEFT ANTERIOR HEMIBLOCK"
DETECTED IN 1968

2 - The second group includes healthy subjects all presenting QRS axis deviation. These patients are of normal weight, are even frequently tall and thin. In most cases, previous records establish that the "abnormal" appearance of the electrocardiogram was present before the age of 25 years and that it remained stable over a long period (8 cases extending over at least 15 years).

It therefore seems reasonable to accept that as well as the familiar positional variations and obvious or probable pathological causes, other left QRS axis deviations exist which present ECG features similar to left anterior hemiblock.

It is established that these features are "at the extreme left of the normal electrocardiogram" and that "in extreme cases, activation of the entire left ventricle may depend entirely on the posterior pathways as in anterior hemiblock" (FERNANDEZ (9)). The situation develops therefore as if the left anterior fascicle was functioning to a limited extent or not at all.

It is on this basis that the authors explain the isolated and stable "left anterior hemiblocks" which they detected.

As LANCASTER wisely recommends (12) we have preferred the term "left axis deviation" to that of "left anterior hemiblock" which implies a pathological cause which remains to be proved. This variant ventricular activation is not exceptional and is encountered frequently during medico-aeronautical clinical examination.

## MEDICO - AERONAUTICAL CONSEQUENCES

I - Of heart disease:

Whatever the nature and etiology, it is obvious that left QRS axis deviation is simply a sign and that the attitude of the clinician depends on the underlying heart disease.

2 - Of a complete right branch bundle block of the bundle of His:

Left QRS axis deviation is a supplementary element which is bound to urge the clinician to great prudence:

a) the unsuitability for acceptance as flying personnel is a conclusion which seems likely,

b) if such abnormality is detected during a periodic review check up, the clinical expert must consider two possibilities:

- the first involves subjects whose former ECG record includes left axis deviation and whose QRS axis remains more or less the same, presenting a "minor type of left delay " in FERNANDEZ' terms. In our opinion these cases should be considered as isolated blocks of the right bundle branch. The usual prognosis is favourable. Even though studies involving endocavitary recordings may sometimes contradict each other, this traditional concept can be retained.

LANCASTER (12) investigating 37 patients of the U.S. Air Force presenting a right bundle branch block subjected them to extremely thorough haemodynamic and angiographic tests and found that 34 of them were retained as suitable for airborne service with no restrictions. The subjects merely being reviewed annually.

The authors adopt virtually the same approach.
External cardiovascular investigations with a vectocardiogram, and a complete metabolic assessment are performed. Temporary unsuitability is declared for a six month period. After this observation period, in the absence of any pathological factors and continuing stability of recordings, we are generally favourable to the continuing service, but with the exclusion of the post of pilot of a high performance aircraft or single pilot function.

Monthly and then three-monthly electrocardiographic monitoring is required.

- the other possibility concerns subjects whose ECG record had been strictly normal on usual criteria and in whom a right bundle branch block and left anterior hemi-block appeared simultaneously.
These cases can be considered as bifascicular blocks and prognosis remains in suspension. Literature data agree that there is a danger of development into complete atrio-ventricular block in a high proportion of cases. In our opinion unsuitability for flying personnel posts should be proposed.

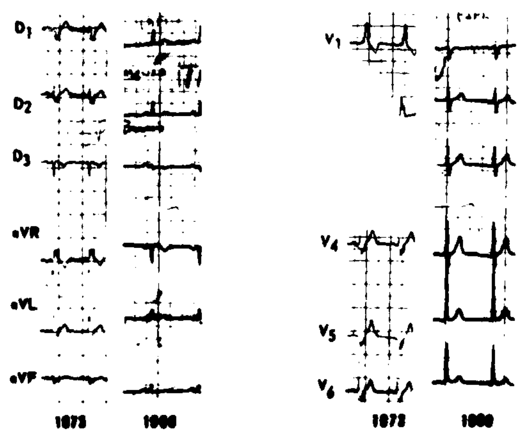
As well as the investigations already listed, the examination should include an accurate study of atrioventricular conduction by means of recording of the action potential in the bundle of His. This risk-free examination has become commonplace and investigates atrioventricular conduction accurately by means of the remaining specific tissue.

Only this examination, which can establish that left branch conduction is satisfactory, can overturn a declaration of unfitness.

A decision with such major consequences cannot be based on the contradictory data in the literature (4-5-7-9-11-12-13-15).

3 - <u>The electrocardiographic aspects of isolated left anterior hemi-block can be divided into two categories:</u>

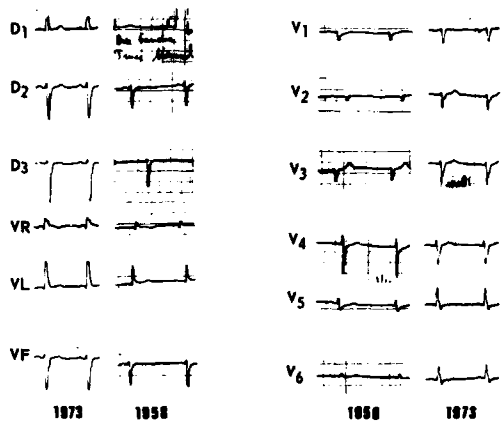
a) those which appear to be acquired in subjects previously presenting a normal electrocardiogram
In this case, the logical attitude seems to be the same as that adopted in cases in which a right branch bundle block develops.




SPA ... François, 39 years, 1.72 m, 71 kg.
CRBBB + Â QRS left
Stable since 1971

b) left deviations of the QRS axis with or without the other criteria advanced for left anterior hemiblock in young subjects, detected during the medical check up for admission to a post as flying personnel.

Whilst taking every possible precaution to ensure the absence of any cardiac or metabolic disease factor, but without resorting to invasive methods, which we hold to be unnecessary here, we think that these are non-pathological variants of ventricular activation and we propose that such subjects are suitable for inclusion as flying personnel.




SPA ... Albert, 34 years, 1.80 m, 92 kg.
LAH
Axis unchanged since 1958
QRS ENLARGEMENT

IV - WOLFF-PARKINSON-WHITE syndrome

V - ATYPICAL VENTRICULAR REPOLARISATION

Please see the detailed study elsewhere in this review.

BIBLIOGRAPHY


1 - **BAHL ( O.M.P.) ; WALSH (T.J.) ; MASSIE (E) .**
**Left axis deviation. An electrocardiographic study with post mortem correlation.**
**Brit. Heart J. 1969, 31, 451-456**

2 - **BLONDEAU (M) ; LENEGRE (J)**
**Bloc atypique de la branche droite.**
**Masson et Cie. Paris 1970**

3 - **BRODSKY (M) ; DELON (N) ; DENES (P ) ; KANAKIS (Ch) ; ROSEN (K)**
**Arrhytmias documented by 24 hours continuous electrocardiographic monitoring in 50 male Medical Students without apparent heart disease.**
**Am. J. Cardiol. 39, 390, 1977.**

4 - **CLEMENTY (J) ; BROUSTET (J.P.); CHOUSSAT (A) ; BESSE (P) ; DALLOCHI (M) et BRICAUD (H).**
**Etude du vecteur initial de QRS dans les troubles de la conduction intraventriculaire**
**Arch. Mal. coeur et vaisseaux. 1973, 66 , 9, 1179-1192**

5 - **COUMEL (Ph) ; ATTUEL (P) ; SLAMA (R) ; BOUVRAIN (Y)**
**L'enregistrement électrocardiographique continu.**
**Intérêt clinique , diagnostique, et thérapeutique.**
**Arch. Mal. Coeur 68, 941, 1979.**

6 - **DELOUSTAL (A)**
**Rôle de la vagotonie dans les troubles de la conduction cardiaque du personnel navigant.**
**Thèse, Paris, 1979.**

7 - DIDIER (A) ; CARRE (R) .
Les difficultés posées dans l'expertise du personnel par la déviation à gauche de l'axe de QRS et ses rapports avec le concept d'hémibloc antérieur gauche.
AGARD, C.P., 232, 1978.

8 - DJIANE (P) ; EGRE (A) ; BORYM ; SAVIN (B) ; MOSTEFA (S) et SERRADIMIGNI (A).
L'enregistrement électrocardiographique chez les sujets normaux.
Arch. Mal. Coeur. 72, 655, 1979.

9 - FERNANDEZ (F)
Les hémiblocs ventriculaires gauches.
Rev. Prat. 1973, 23, 33, 2995-3022.

10 - GRANT (R.P.)
Clinical electrocardiography
New York, Mac Grax Hill, 1957.

11 - GUEROT (C) ; COSTE (A) ; VALERE (P.E.) ; MOTTE (G) et TRICOT (R).
Enregistrement de l'activité du tronc du faisceau de His et de ses branches dans des troubles de conduction intra-ventriculaire.
Arch. Mal. Coeur - 1973, 66, 3, 269-283.

12 - LANCASTER (M.C.) , STRECHTER (E) ; MASSING (G.K.)
Acquired complete right bundle branch block without over cardiac disease.

13 - LECLERCQ (J.F.) ; COUMEL (Ph).
L'enregistrement Holter en rythmologie
Docum. med. Labor. LABAZ 1980

14 - LENEGRE (J)
Contribution à l'étude des blocs de branche comportant notamment les confrontations électriques et histologiques.
Paris - 1958, J.B. BAILLITRE et Fils

15 - NARULA (O.S.) ; SAMET (P)
Right bundle branch block with normal left or right axis deviation.
Am. J. Med. 1971, 51, 432-455

16 - PERNOD (J) ; FRANCOZ (P) ; KERMAREC (J) ; CARRE (R).
L'électrocardiogramme du sujet de 20 ans.
Rev. Corps Santé - 9 , 2, 165-179.

17 - PRYOR (R) ; BLOUNT (S.G.)
The clinical significance of true left axis deviation. Left intraventricular blocks.
Am. Heart J. - 1966, 72, 391.

18 - OSTANDER (L.D. )
Left axis deviation : prevalence, associated conditions, and prognosis.
An epidemiologic study.
Ann. Intern. Med. - 1971, 75, 23-28.

19 - PLAS (F) .
Guide de Cardiologie du Sport.
J.B. Baillières Editions, Paris.

20 - RANGANATHAN (N) ; DHURANDHAR (R) ; PHILLIPS (J.H.) ; WIGLE (E.D.)
His bundle electrocardiogram in bundle branch block.
Circulation, 1972, 45 , 2, 277-294.

21 - REMAMBOT (J) ; BERTRAND (E).
Les hémiblocs de la branche gauche du faisceau de His.
Med et Armées - 1973, 1 , 7 , 49-54.

22 - SCANLON (P.J.) ; PRYOR (R) ; BLOUNT (S.G.)
Right bundle branch block associated with left superior or inferior intra-ventricular block.
Clinical setting prognosis and relation to complete heart block.
Circulation 1970, 52 , 1123.

23 - ROSENBAUM (M.B.) ; ELIZARI (M.V. ) ; LAZZARI (J.O.).
Les hémiblocs.
Ed. Plaidos, 1968, Buenos-Aires.

# CHAPTER 2

## VENTRICULAR PRE-EXCITATION SYNDROMES

by J. Droniou*

Ventricular pre-excitation (VPE) syndromes constitute a group of conduction disorder involving premature activation of all or part of the ventricles by the normal sinus node excitation wave. These syndromes may be asymptomatic, consisting of electrocardiographic signs, or may be complicated by arrhythmias which may be serious. The asymptomatic forms are a source of problems in the examination of flying personnel for two reasons :

- Some electrocardiographic abnormalities suggestive of pre-excitation are ambiguous
- Prognosis is difficult to establish

### I - CURRENT CONCEPTS OF VPE SYNDROMES

The VPE syndromes arise from two essential mechanisms. In some cases there is an accessory conduction pathway, remnant of an embryological system, which partially or totally shortcircuits, or bypasses, the physiological AV node-His pathway and competes with it for transmission of the sinus node activation into the ventricles. In other cases there is no evidence of any anatomical by pass and the pre-excitation appears to originate in a purely functional phenomenon of accelerated atrioventricular conduction.

The electrocardiographic effects depend on the topography and electrophysiological properties of the accessory pathway when there is one. Two types of abnormalities occur and these may not be associated :

- shortening of the P-R interval, reflecting either an anatomical bypass of the A-T node (ATN), or else accelerated nodal conduction;
- the pre-excitation delta wave, widening the QRS wave with a loss of its onset component and reflecting premature activation of a portion of the ventricular myocardium via the accessory pathway (AP) within it. The terminal section of the QRS is normal and corresponds to activation of the remainder of the ventricle via the A-V node-His pathway (NHP), occurring at the normal times (but after that via the AP). The QRS complex really represents a fusion complex, the width of which depends on the amount of pre-excited myocardium, reflected by the delta wave.

#### I - A. CLASSIFICATION OF VPE SYNDROMES

3 groups can be distinguished:

#### I - A. 1. Anomalous atrioventricular connections

Commonly known as KENT'S BUNDLE, these form a bridge from the atrium to the homolateral ventricle (complete AV-bypass). The AP may be situated on the right or left and may be anterior or posterior, septal or lateral. The electrocardiographic sign of its presence is the WOLFF-PARKINSON-WHITE syndrome (WPW).

#### I - A. 2. Accelerated atrioventricular conduction (AAVC)

The electrocardiographic sign is the short P-R interval described by CLERC, LEVY and CRISTESCO (5) and later by LOWN, GANONG and LEVINE (14), which is usually known as the LOWN, GANONG and LEVINE syndrome.

The corresponding mechanisms are ambiguous:

- anatomic bypass of the ATN either via the JAMES atrio-nodal fibres; or via atrio-His fibres as described by LEV and by BRECHENMACHER.
- insufficient development of the ATN
- a purely functional phenomenon of accelerated nodal conduction.

#### I - A. 3. VPE of MAHAIM fibres

This type of VPE, is less common and is related to the presence of anomalous AV node-ventricular or His-ventricular pathways.

* Médecin-en-Chef
Chef du Service de Cardiologie de l'Hôpital
d'Instruction des Armées du Val-de-Grâce
74 bd. de Port-Royal
75230 PARIS CEDEX 05 FRANCE

I - B. MECHANISM OF EPISODES OF TACHYCARDIA

These episodes sometimes occur as complications of the VPE syndromes and they obey two major mechanisms:

I - B. 1. Regular episodes of tachycardia with reciprocal rhythm.

The reentrant circuit follows the AV node-His and the accessory pathways. The initiation mechanism is an extrasystole which may be of various origins and which finds one of the pathways open and the other still refractory. This reentry is favoured by widely differing refractory periods of the two pathways. The reentry may also be intra-nodal and this explains the possibility of reciprocal tachycardia in the absence of any anatomical bypass.

I - B. 2. Episodes of atrial tachycardia:

Atrial flutter or fibrillation may be transmitted to the ventricles via the accessory pathway or via the AV node-His pathway. The severity of these episodes depends on the refractory period of the accessory pathway.

Ventricular arrhythmias are generally a complication of atrial tachycardia entirely transmitted to the ventricles via an AP with short refractory period.

I - B. 3. Role promoting theft:

The prolonged and extreme acceleration and Gs met with in the flying of high performance fighter planes may, in theory at least, constitute a factor promoting arrhythmias. They result in the following elements:

1) a series of phases of tachycardia and of bradycardia. These variations in the duration of the nodal cycle and in the vagal-sympathetic modifications which underly them may create reentry conditions by altering the refractory periods of the two pathways;
2) myocardial hyperexcitability, the source of extrasystoles, may initiate reciprocal tachycardia;
3) myocardial hypoxia, as a result of reduced coronary artery flow, may promote the ventricular desynchronisation phenomena such as tachycardia and result in ventricular fibrillation.

In general, aeronautical stress factors, combined to a maximum effect in fighter planes, result in sympathetic stimulation and catecholamines release similar to those produced by effort, the usual factor triggering arrhythmias in VPE syndromes.

II - WPW SYNDROME

This is the VPE syndrome which has been studied in greatest detail and which carries the greatest risk of paroxysmal tachycardia (PT). If this feature is detected during the selection examination, the candidate is classified as unsuitable for inclusion in flying personnel. In fact, some patients get through the selection process because of diagnostic inadequacies.

II - A. DIAGNOSTIC PROBLEMS DURING SELECTION

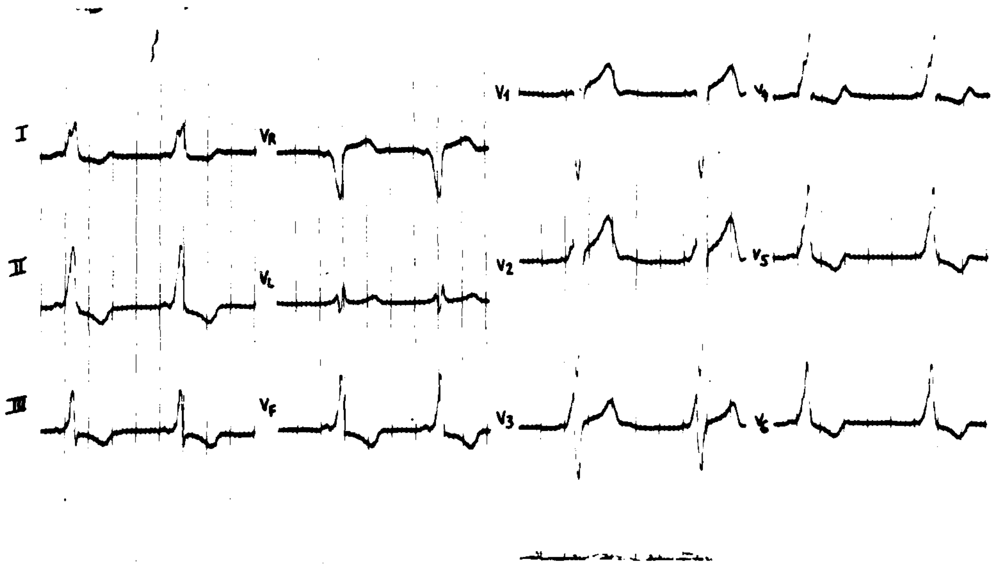
These can be deduced from the very variable incidence of WPW syndrome in statistics from various sources: from 0.5‰ during health check ups (periodic examinations in apparently asymptomatic subjects) to 3.25‰ in some hospital units. The studies in flying personnel reveal an incidence of between 0.99 and 3 ‰ (1,3,9,16,18,19).

The electrocardiographic sign results as we have said from competition between the AP and the Node-His pathway. The outcome depends obviously on several factors:

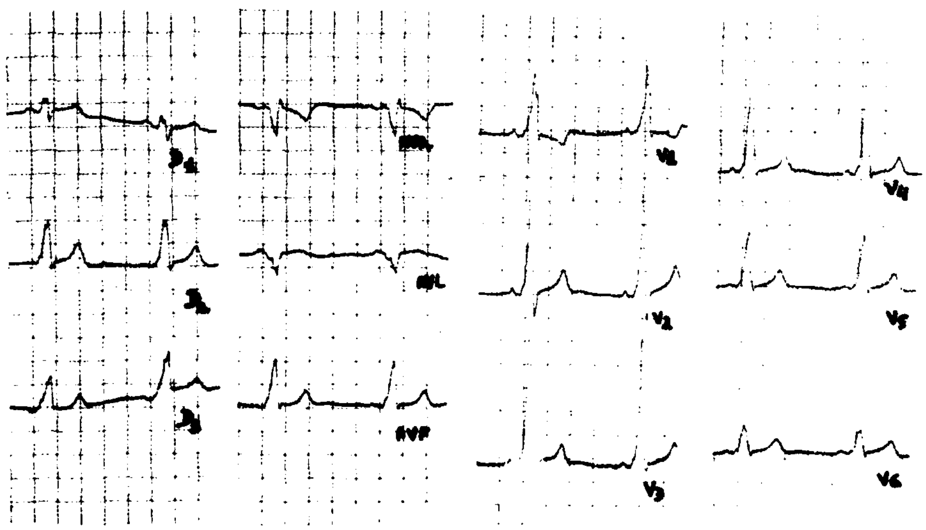
- the refractory periods (RP) of the two pathways
- the atrial point of insertion and the ventricular point of emergence of the AP,
- changes in the vago-sympathetic tone and of the sinus node rhythm which could change the RP and the speed of conduction of the input in the two channels in any way.
  This explains the numerous electrocardiographic variants which exist, some of which may not be recognized.

II - A. 1. Typical ECG records

These are readily diagnosed from the association of 5 criteria (Figure 1)




I. A. : TYPE B WPW



I. B. : TYPE A WPW

Figure 1 - WPW syndrome: typical ECG recordings
1 A : type B; 1 B : type A.

- normal P waves arising in the sinus
- shortened PR interval, or rather P-delta interval, less than 0.12 seconds
- large QRS greater than 0.12 seconds, with an initial delta wave
- normal PJ interval
- secondary repolarization disturbances, less essential.

The polarity of the delta wave and of the QRS complex varies depending on the AP pathway. Various electrocardiographic classifications can be suggested, we will consider only two:

- ROSENBAUM's classification of type A and type B: Type A is characterised by an exclusive or predominant V1 R wave. This corresponds to left VPE. Type B, which corresponds to a right VPE is characterised by predominantly negative QRS complexes on the right precordials. In fact many WPW cases cannot easily be classified on this system.
- a classification depending on the polarity of the delta wave has been established on the basis of surgical epicardiac mapping data:

  . V1 positive delta wave : left VPE
  . V1 negative or isodiphasic delta wave : right VPE
  . D3 negative delta wave : septal VPE (right or left)
  . D3 positive delta wave : lateral VPE (right or left) .

This is of course a very rough classification but it is useful in clinical practice.

Even though the pathological nature of the ECG is obvious, these typical patterns *may result in diagnostic errors:* confusion with the sequellae of myocardial infarctus, with right ventricular hypertrophy (left VPE) or with a left bundle branch block (right VPE) are possible.

II - A. 2. *Mild or minor forms:*

These consist of a QRS complex showing little or no enlargement, a slight delta wave which may sometimes be replaced by the near disappearance of the physiological wave on some leads (see figure 2). They may be confused with a short PR syndrome, and even not detected at all if the PR interval is borderline. Such a pattern is frequent in VPE of the left lateral Kent bundles. In this form the input of sinus node origin takes longer to reach the left atrial point of insertion of the AP than to reach the NHP.

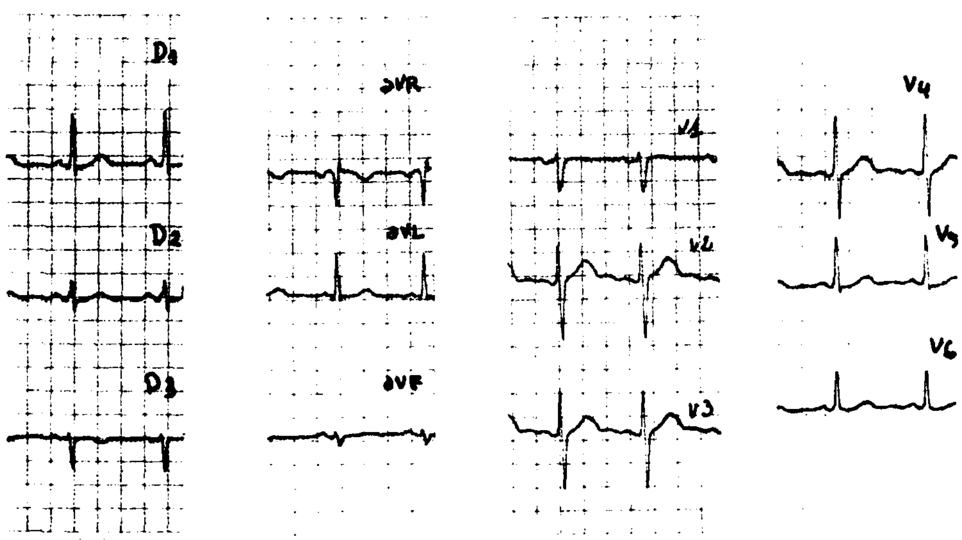



Figure 2 WPW syndrome: minor form
The diagnosis can be suspected from the D2, V5, V6 leads.

II - A. 3. Intermittent forms:

These are also frequent in *from 17% (4) to over 35% (6-15) of* cases depending on the authors. In a statistical study carried out at the Centre Principal d'Expertise du Personnel Navigant de Paris, RICHART (16) detected 18% of these forms. However the VPE pattern may sometimes occur on the *same recording* with normal patterns (see figure 3) but may be revealed only occasionally, the ECG being normal at several successive examinations.

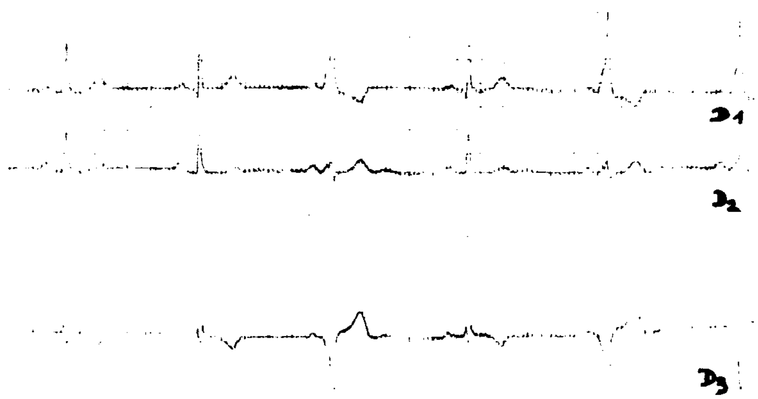



Figure 3 - WPW syndrome: intermittent form - alternation of normal complexes with pre-excitation complexes.

II - A. 4. Masked forms:

In these forms the VPE is not evident from the surface ECG. Such forms remain undetected and may be discovered only when so.e rhythmic disturbance occurs. They result from two mechanisms:

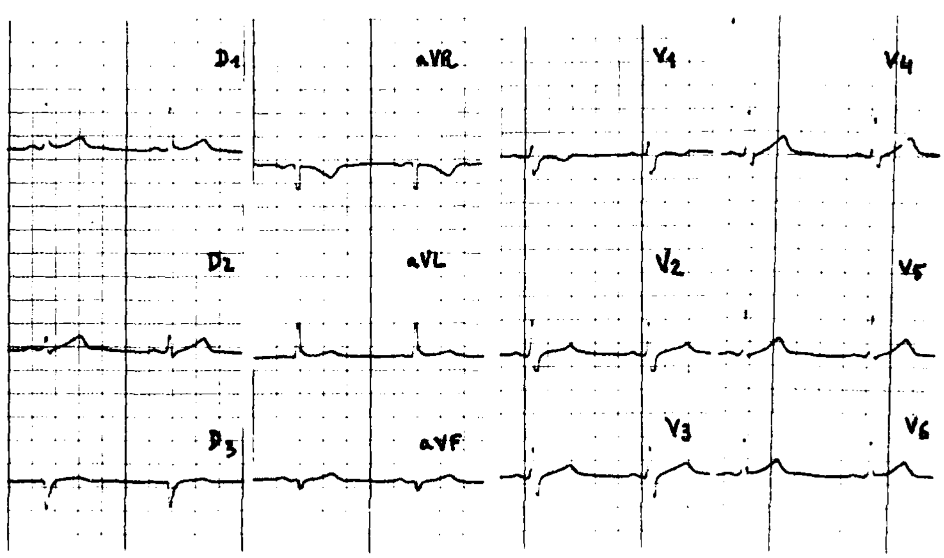



Figure 4 - WPW syndrome: masked form. PR interval 0.13 sec: slight thickening of the foot of the R wave on some leads.

a) the AP remains permeable to the sinus node activation wave in the antegrade direction (atrioventricular) but does not readily show itself either because its refractory period is much longer than that of the NHP, or especially in the case of the left lateral Kent bundle, particularly if there are also present intra-atrial conduction problems (Figure 4).

b) in other cases, the AP is the site of a permanent block in the anterograde direction but remains permeable in the retrograde direction and may be involved in the reentry circuit. Patients presentingtrue BOUVERET diseases correspond to this mechanism.

II - A. 5. Diagnosis of atypical forms

The physiopathology of the WPW syndrome explains that by means of various external manoeuvres or pharmacological interventions to increase a mild VPE or to reveal an intermittent or even masked VPE. Such interventions include:

- vagal manoeuvres such as the oculocardiac reflex which slows conduction in the node-His pathway without affecting the AP conduction;
- the injection of methoxamine, of neosynephrin or better still adenosine triphosphate (adrenergic drugs);
- the effort test, which results in sympathetic stimulation and catecholamine release which may either increase the VPE or else cause it to disappear if the refractory period is long;
- simple variations in the heart rate may sometimes suffice to trigger VPE.

Endocavitary electrophysiologic exploration is only carried out in complicated cases and in principle has no place in the clinical examination of flying personnel. This reveals:

- a normal AH interval (atrio-His conduction time) in excess of 60 msec.
- a shortened HV interval (His-ventricular conduction period) of no more than 30 msec, since ventricular depolarisation begins prematurely. The HV interval is shorter the greater the VPE, at maximum effect H may be hidden in the ventriculogram.
- atrial stimulation at rising frequency and the method of atrial extra stimulus can be used to increase and reveal mild minor or masked VPE with persistent antegrade conduction. Endocavitary exploration is the only method capable of detecting masked forms with permanent antegrade block. This investigation also gives information concerning the electrophysiological properties of the two pathways and the topography of the AP.

II - B. PROGNOSTIC DIFFICULTIES IN REVIEW CHECK UPS

Whatever procedure is adopted, WPW syndromes will be discovered during some subjects' careers. When episodes of tachycardia are also present, the presence of WPW results in unfitness. In other cases the decision is based on an assessment of the risk in function of the pre-excitation in itself and of the aeronautical field involved.

II - B. 1. Prognosis of the WPW syndrome

The detection of an isolated WPW abnormality in an experienced flight officer does not necessarily have a negative significance. The frequency of arrhythmias which varies between 4.3% and 90% depending on the source of the statistics (7), is less than 15% in flying personnel (3-16-18-19). Furthermore, the statistics from aeronautical sources and involving a follow up over several years indicate a low incidence of episodes of tachycardia (3-19) and zero mortality directly attributable to WPW syndrome (19). Finally it should be noted that in most groups studied (6-8-10) the episodes began before the age of 30 years in between 70 and 82% of cases.

The optimistic outlook which would seem to result from these aeronautical studies should however be tempered somewhat. A diagnosis based on the interview is always dubious when it comes to an expert clinical examination and it is probable that some subjects who have had occasional episodes of mild and shortlived tachycardia still continue to fly. Furthermore statistically 20 to 30% of patients do present their first attacks of tachycardia after the age of 30.

The WPW syndrome is also combined in 20 to 30% of cases with congenital or acquired cardiographic abnormalities, two of which should be considered since they promote rhythm disturbances and may pass unrecognized. Primitive myocardiopathies, especially obstructive hypertrophic myocardiopathy, may result in a false appearance of pre-excitation or be associated with an authentic VPE.

Mitral valve ballooning may also accompany WPW syndrome, generally of type A, in 75% of cases according to data from some studies (7). Knowledge of the possibility of these two associations justifies systematic echocardiography in any flying personnel staff members presenting WPW syndrome.

Finally and above all, it should be remembered that the first episode of tachycardia, even if it occurs late, may be serious from the outset and even result in sudden death.

Very mild episodes of paroxysmal tachycardia may sometimes be accompanied by functional symptoms which may disturb consciousness: lipothymic states or brief syncopes. Such incidents are sometimes found in the case history of subjects presenting WPW syndromes but who do not report episodes of tachycardia.

The major danger is that of episodes of atrial tachycardia, flutter or particularly atrial fibrillation (AF).

According to hospital statistics AF occurs in between 11.5 and 39% of WPW cases (7), this figure may be somewhat over-estimated because of the selection of subjects. In particular, AF may definitely occur in young subjects with a healthy heart in whom the AP is the only factor promoting its onset. If the AP has a very short refractory period the AF may also be fully transmitted to the ventricles and thus produce MALIGNANT ATRIAL FIBRILLATION with high ventricular frequency (figure 5) which is always poorly tolerated and carries a constant risk of sudden death by transformation into ventricular fibrillation (7).

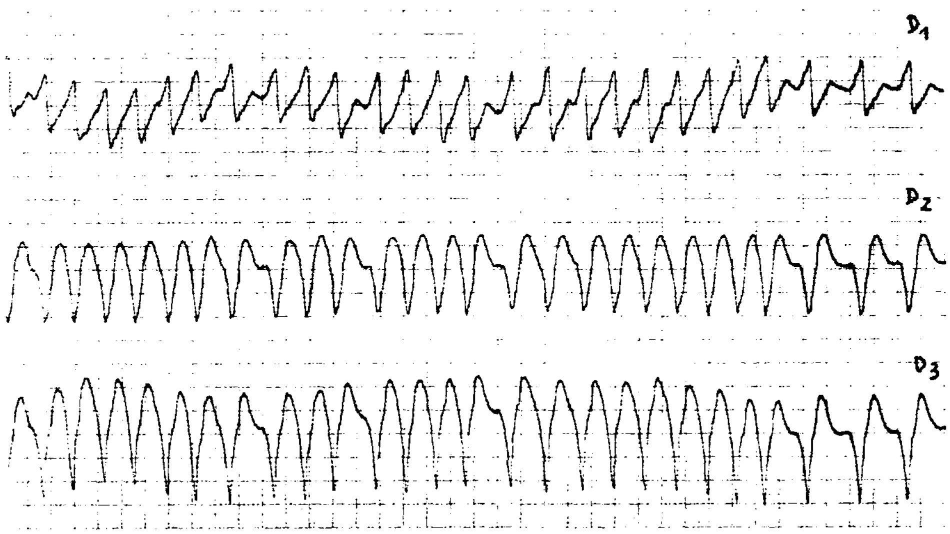



Figure 5 - Episode of tachyarrhythmias due to atrial fibrillation (same patient as figure 4)

An accident of this type may be the first and last in a hitherto asymptomatic subject presenting a typical, intermittent, mild or masked VPE. Sudden death in the WPW syndrome results from such episodes. The risk is evaluated by LEPESHKIN (11) at 1%, a figure that LAHAM (10) considers too high, but other authors give still higher figures. It is in any case unpredictable .

II - B. 2. Assessment of the risk

In practice how can we detect the high risk subjects amongst those presenting WPW syndrome, who are particularly exposed to arrhythmias and especially severe arrhythmias? Age, the absence of any associated heart disease, the appearance of the recording which may be typical, atypical or masked, and the absence of any past history of arrhythmias do not constitute solid prognostic arguments (7).

Only endocavitary electrophysiological exploration is able to provide definite evidence by establishing the refractory periods of the two pathways and by demonstrating a short refractory period of the AP and the hyperexcitability of the myocardium resulting in easy triggering of paroxysmal arrhythmias of various types and especially of AF, is really decisive. And even this exploration is not absolutely decisive since it provides only an instantaneous picture of the electrophysiological conditions which may vary with time under the influence of various factors.

Some non-invasive examinations can provide useful prognostic indications:

1) Echocardiography can reveal any abnormalities in the movement of the septal and posterior walls of the left ventricle which vary in function of the form of VPE and are of particular use in detecting any possible associated heart disease.
2) The 24-hour monitoring of the electrocardiogram may detect hyperexcitability of the myocardium in the form of frequent extrasystoles or even brief episodes of tachycardia.
3) The exercise test may sometimes induce an episode of tachycardia (4-12). The persistence of the VPE at high frequencies accompanying maximum effort is particularly indicative of a short refractory period AP whereas a disappearance of the VPE suggests a long RP, a positive prognostic factor (figure 6).

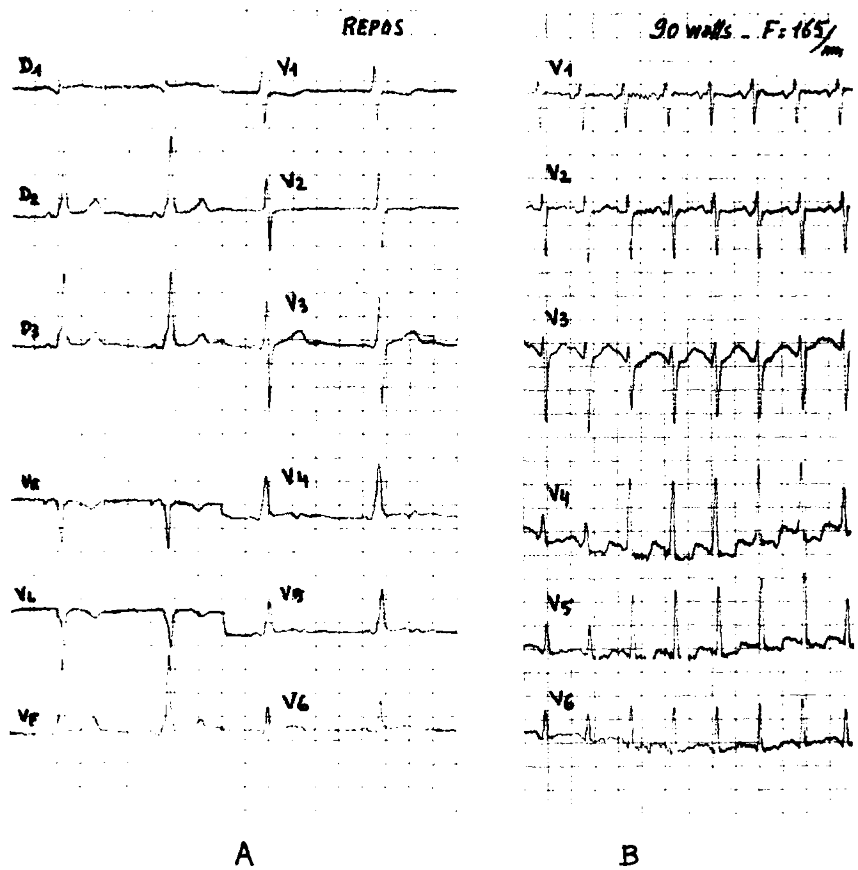



Figure 6 - effort test

A - base line
B - submaximum effort recording
Narrowing of QRS complexes

Key: repos = rest

4) Specific aeronautical tests may be employed: use of a depression caisson with hypoxia (19), exposure to acceleration + Gz in the centrifuge in order to investigate the reaction of patients in a situation as near as possible to actual conditions

II - B. 3. Practical approach

a) to selection:

The mere presence of the WPW syndrome results in disbarring of the candidate. Some minor forms should not be overlooked. These may take the form of a short PR interval or a barely detectable delta wave with a PR at the limit of normality. Routine performance of the oculocardiac reflex, a simple, rapid and hasard free procedure, clarifies some unclear forms. However, it is certain that some mild, intermittent or masked forms of WPW do get through the selection filter.

b) to review check up:

Any suspicion of paroxysmal episodes disbar the candidate. For asymptomatic subjects, in the light of the present impossibility of any certitude of prognosis, we recommend the following attitude:

1) Disbarring from the role of pilot in high performance fighter planes because of the high risk factors this entails.
2) Fitness for pilot roles in transport and liaison aircraft, and helicopters, on condition that there is a co-pilot and that the electrocardiogram, 24-hour electrocardiographic monitoring and exercise test are all normal.

The authors believe that an endocavitary electrophysiological exploration may be justified. The detection of myocardial hyperexcitability, especially if the refractory period of the AP is short, would entail disbarring from any pilot role.

3) For other flying personnel categories, the only essential criterion is the absence of episodes of paroxysmal tachycardia.

## III - / SHORT PR INTERVAL SYNDROME /

This is reflected by a PR interval of less than 0.12 seconds and a narrow QRS without any delta wave. The detection of such abnormalities poses various questions which are far from being answered:

. concerning their frequency
. concerning their significance
. concerning the increasing risk

We will consider these three aspects in turn.

### III - A. FREQUENCY

This syndrome is more frequent than the WPW syndrome. SEARS and MANNING (18) found a frequency of 1.5% in subjects aged 18 to 24 years. LOMBARDI and MASINI (13) found a frequency of 0.89% in 4320 ECG recordings of hospitalised patients. The Paris CPEMPN detected this abnormality in 2% of the subjects examined (according to CARRE).

### III - B. SIGNIFICANCE

This feature is not unambiguous.

1) Some short PR intervals correspond to minor WPW syndromes. Attention should be paid to a slight thickening of the foot of the QRS, and the disappearance of the physiological Q-wave on some leads. Vagal manoeuvres and on occasions exercise tests may reveal the existence of a Kent bundle.
2) Other short PR interval syndromes reflect ACCELERATED ATRIOVENTRICULAR CONDUCTION which can be established or eliminated only by endocavitary electrophysiological exploration revealing the following features:
   - an AH interval of less than 60 msec
   - a normal HV interval
   - and, during atrial stimulation at progressively increasing frequencies up to 200 per minute, the persistence of 1/1 atrioventricular conduction with little or no change in the AH intervals up to these high frequencies. Several features of varying significance may be masked by this electrophysiological syndrome: accessory atrio-His or atrio-nodal pathways, insufficient development of the ATN or purely functional phenomena.
3) In some subjects presenting short PR, there is no pre-excitation and findings of the electrophysiological exploration are normal (17).

It is reasonable to suppose that patients in the third group are no more liable to arrhythmias than the normal population. Unfortunately the absence of routine endocavitary electrophysiological exploration makes it impossible to determine the relative proportions of these three categories of short PR syndromes.

### III - C. INCREASING RISK

Episodes of tachycardia are less frequent than in WPW syndrome, of the order of 11.5% to 14% of cases in the studies of LOWN, GANONG and LEVINE (14), of LOMBARDI and MASSINI (13) and of CLERC (5). The subjects investigated by SERGE and MANNING (18) did not include any case. This lower incidence can doubtless be attributed in part to the inclusion of a group of subjects without VPE.

Arrhythmic episodes are of various types and some are potentially serious: accelerated atrioventricular conduction seems to be the essential factor for severity, explaining the frequently high heart rate during reciprocal tachycardia and atrial tachycardia. According to BENDITT (2), this also explains the serious ventricular arrhythmias which are sometimes noted. These may be tachyarrhythmias or ventricular fibrillations :

- either due to rapid transmission of atrial fibrillation to the ventricles
- or through the intermediary of an atrial extrasystole rapidly transmitted to the ventricles and finding them in a vulnerable state.

There is a risk of sudden death: LOWN GANONG and LEVINE (14) reported two cases in patients exposed to episodes of atrial fibrillation.

III - D. PROBLEMS ENCOUNTERED IN THE EXPERT MEDICAL REPORT

The facts explain the problems encountered in the expert report on short PR syndromes, and on which there is no consensus.

1) At selection

Two attitudes are possible:
- either the elimination of all subjects presenting short PR syndrome; this amounts to the rejection of 1 or 2% of candidates,some of whom are healthy subjects;
- o: the elimination of only subjects with paroxysmal tachycardia, with the attendant risk of failing to recognize mild WPW or of allowing subjects with accelerated atrioventricular conduction and exposed to the risk of possibly serious arrhythmias to embark on a career in aeronautics.

The impossibility of certitude of prognosis without recourse to endocavitary exploration should result in the same severe attitude to clearly defined short PR as to WPW.

2) Review examinations

The suspicion of episodes of tachycardia does of course result in disbarring. The discovery of an isolated PR in the pilot of a high performance fighter plane should, in our opinion, if the echocardiographic recording, the Holter monitoring and exercise test give normal results, lead to an endocavitary electrophysiological exploration and to aeronautical stress tests. If the subject's reactions are normal and if the endocavitary exploration demonstrates the absence of accelerated atrioventricular conduction, the subject can be passed as suitable and the performance of an invasive test during an expert report is justified.

For other personnel categories, the same approach should be adopted as to WPW.

IV - / VPE INVOLVING MAHAIM FIBRES/

This is detected in the surface ECG from the following features:

- a PR of more than 0.12 seconds, showing that the AP arises above the ATN;
- a QRS complex extended by a delta wave, resulting from the ventricular insertion of the AP (the VPE is generally mild).

This type of VPE is very rare, but it is possible that some cases are unrecognized. It carries less risk of arrhythmias than the other two forms but may, in a few cases, promote reentrant ventricular arrhythmias. Diagnosis is confirmed by endocavitary exploration revealing:

- a normal AH interval
- a short HV interval
- the response to atrial stimulation depending on the type of fibres involved.

In any case, the attitude adopted at selection can be the same as for other VPE syndromes. At review check ups in subjects who are generally asymptomatic, the suitability for pilot clearance can be maintained except in the case of pilots of high performance aircraft, who must be disbarred.

BIBLIOGRAPHY


1. **AVERILL (H) , FOSMOE (RJ) ; LAMB (LE)**
**Electrocardiographic findigs in 67 375**
**Asymptomatic subjects**
**IV. WPW syndrome . AM. J. Cardiol. 1960, 6 , 108**

2. **BENDITT ( DG) ; PRITCHETT (ELC) ; SMITH (WM) ; WALLACE (AG) ; GALLACHER (JJ)**
**Characteristics of atrioventricular conduction and the spectrum of arrhythmias in LGL syndrome**
**Circulation 1978, 57, 454**

3. **BERKMAN (NL) and LAMB (LE)**
**The WPW electrocardiogram. A follow-up study of five to twenty-eight years**
**New Engl. J. Med. 1968, 278 , 492**

4. **BROUSTET (JP) ; LEVY (S) ; VIRCOULON (B) ; GUERN (P) ; CLEMENTY (J) ; CHOUSSAT (A)**
**Syndrome de WPW : comportement au cours de l'épreuve d'effort limitée par les symptomes.**
**Arch. Mal. Coeur. 1979, 72 , 625**

5. CLERC (A) ; LEVY (R) ; et CRISTESCO (C)
A propos du raccourcissement permanent de l'espace PR de l'ECG sans déformation du complexe ventriculaire
Arch. Mal. Coeur 1938 , 31 , 569.

6. FLENSTED-JENSEN (E)
WPW syndrome. A long-term follow-up of 47 cases.
Acta. Med Scand. 1969 ; 186 , 65

7. GALLAGHER (JJ) ; PRITCHETT (ELC) ; SEALY (WC) ; KASELL (J) ; WALLACE (AG )
Les syndromes de Pré-excitation.
Acquisitions Nouvelles Pathologie CV 1978, 20 , 525

8. GAUSI (GC) et coll.
Syndrome di WPW. Estudio di 70 casos
Arch. Inc. Mex. 1966 , 36 , 74

9. HISS (RG) and LAMB (LE)
Electrocardiographic findings in 122. 043 individuals
Circulation 1962, 25, 947

10. LAHAM (J)
Actualités électrocardiographiques
1969, 267 p ; Maloine-Paris

11. LEPESCHKIN (E)
The WPW syndrome and others forms of pre-excitation
1962. Cardiology, edit. by Al. LUISADA
MAC GRAW-Hill Publishers ; NEW YORK

12. LEVY (S) ; BROUSTET (JP) ; CLEMENTY (J) ; VIRCOULON (B) ; GUERN (P) ; BRICAUD (H).
Syndrome de WPW : corrélations entre l'exploration électrophysiologique et l'effet de l'épreuve d'effort sur l'aspect électrocardiographique de pré-excitation.
Arch. Mal. Coeur. 1979, 72 , 634

13. LOMBARDI (M) e MASINI (G)
Rilievi elettrocardiografic nella sindrome di WPW ( osservazione sur 34 casi)
Malattie Cardio. Vasc. 1966, 7 ; 387.

14. LOWN (B) ; GANONG (WF) ; LEVINE (SA )
The syndrome of short PR interval, normal QRS complexes and paroxysmal rapid heart action.
Circulation 1952 ; 5 , 693

15. MORTENSEN (V) et Coll.
WPW syndrome
Acta Med. Scand. 1974, 118, 911

16. RICHART (JC) ; CARRE (R) ; SALVAGNIAC (J) ; PLAS (F)
Syndrome de WPW et aptitude au personnel navigant
Rev. Med. Aéro et spat. , 1970, 9 , 15

17. SCHERF (D) ; and COHEN (J)
The atrio-ventricular node and selected cardiac arrhytmias
1974. NEW-YORK. Grune and Stratton.

18. SEARS (GA) and MANNING (GW)
The WPW pattern in routine electrocardiography
Canad. Med. Assoc. J. 1962, 87, 1213

19. SMITH (RF)
The WPW syndrome as an aviation risk
Research Report. US Naval School of aviation medicine.
US Naval Aviation Medical Center. Pensacola. 1963

# CHAPTER 3

# THE EXERCISE ELECTROCARDIOGRAM

by G. Leguay* and A. Seigneuric*

## PART ONE

## - PHYSIOLOGICAL BASES OF THE EXERCISE ECG

The physical fitness of an individual depends in the first instance on his/her ability to use oxygen(22).

### I - MUSCULAR CONTRACTION

Muscular contraction results from the conversion of energy into mechanical energy.

It requires the presence of the following:

- energy-providing substrates
- enzyme substrates
- oxygen

The energy-providing substrates are the carbohydrates and the lipids.

The source of energy is ATF (adenosine-triphosphate). The ATP stores in the muscle are low and if muscular activity is prolonged, ATP is replenished from muscle glycogen, blood glucose and even from lipids (fatty acids).

All these reactions require the consumption of oxygen (aerobiosis) and result in the formation of pyruvic acid.

If intense muscular activity is prolonged, ATP is produced by anaerobiosis from pyruvic acid, which is converted into lactic acid. This produces the sensation of tiredness which forces halting of the exercise.

### II - MAXIMAL OXYGEN CONSUMPTION ($\dot{V}O_2$ max)

The principal factor determining an individual's physical fitness is his/her capacity to use oxygen.

A subject with a high ability to use oxygen in the muscles is able to meet intense and prolonged energy requirements and hence prolonged and intense exercise.

Oxygen consumption ($\dot{V}O_2$) is expressed as litres per minute (l/mn) or as millimetres per kilogram per minute (ml/kg/mn). The second form makes it possible to compare the performance of subjects with different body weights.

The $\dot{V}O_2$ at rest is of the order of 250 ml/mn.

The $\dot{V}O_2$ rises in proportion to increased work done (see figure 1).

The $\dot{V}O_2$ determined during the sixth minute of dynamic exercise involving work W is directly proportional to the work done.

For maximal work = W max., maximal oxygen consumption = $\dot{V}O_2$ max, or aerobic capacity is reached.

* Médecin en Chef
Professeur Agrégé du Service de Santé.

Study carried out by the Service du Médecine Aéronautique et Médecine Interne
Hôpital d'Instruction des Armées D. LAREY
78013 FRANCE

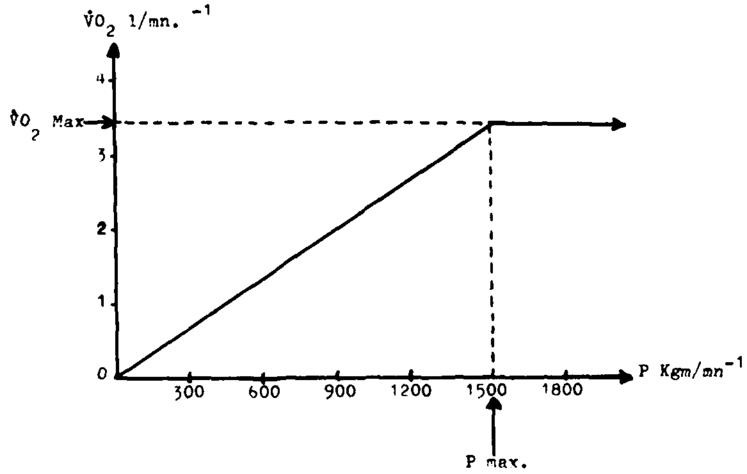



FIGURE 1

Changes in oxygen consumption $\dot{V}O_2$ in function of the work W during exercise (after ECLACHE and BEAURY (12).

For any exertion exceeding W max, and so in excess of the aerobic capacity, the muscle works under anaerobic conditions and this is reflected by a sudden rise in the level of lactic acid in the blood (figure 2), which triggers exhaustion.

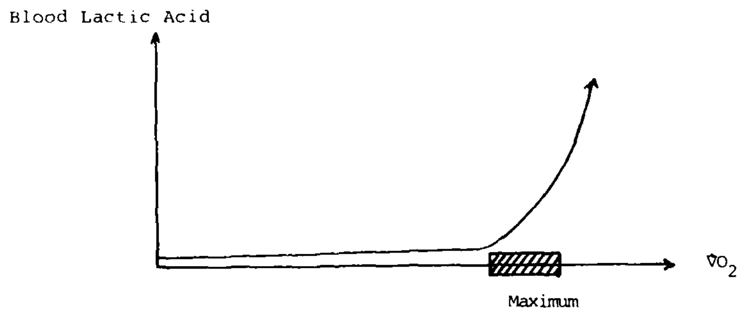



FIGURE 2

Diagram showing the rise of blood lactic acid during exertion involving increasing work output.

- Expressed in ml/mn., the $\dot{V}O_2$ max. may reach 4,000 or even 5,000. FENN obtained a value of 5,350 ml/mn (16).
- Expressed as ml/kg/mn it ranges from 40 to 85.
- The values vary in function of several factors (30).
  - . Age. $\dot{V}O_2$ max. peaks at 15 to 20 years and then tails off. By 60 years it has fallen by one third.
  - . Sex. $\dot{V}O_2$ max. is lower in women because they have lower muscle mass and the level of haemoglobin is also lower.
  - . Type of exercise. $\dot{V}O_2$ max. may be up to 30% higher during muscular exertion of the legs than that of the arms.
  - . Exercise training. $\dot{V}O_2$ max. falls by 25% after three weeks bed rest.

The determination of the exertion $\dot{V}O_2$ max. of an individual is the best index of work capacity and physical fitness.

The $\dot{V}O_2$ max. is the upper limit of the capacity for adaptation of the mechanisms responsible for the supply, transport and use of oxygen (12).

The use of oxygen by muscle tissue requires previous binding to haemoglobin in the lungs and transport in the circulation to the tissue.

## III - EXCHANGES IN THE LUNG

In disease-free conditions, exchanges within the lung are never a limiting factor for oxygen consumption or for exertion (28-31-32).

## IV - CIRCULATORY ADAPTATION TO EXERCISE

The transport of oxygen from lungs to muscle and the removal of metabolites by the blood stream require the calling into play of cardiovascular adaptations which are shown in the diagram below (figure 3). The essential features are cardiac output and arteriovenous oxygen difference.

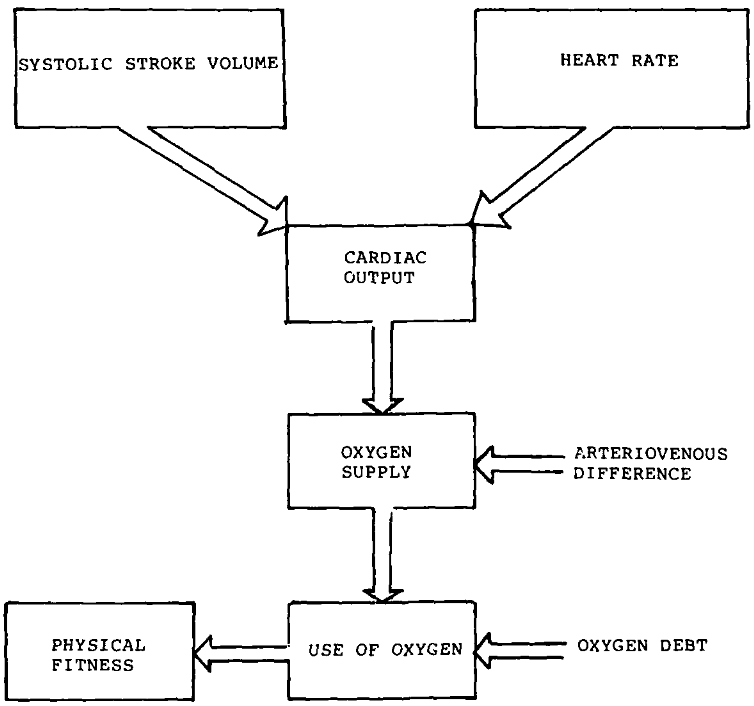



FIGURE 3

Cardio-circulatory factors determining oxygen utilisation capacity (aerobic capacity) after R. HENANE et al (22).

Cardiovascular factors govern transport and distribution of $O_2$ and hence the $\dot{V}O_2$ max.

This leads to two basic concepts:

A) To a large extent, it is the cardiovascular system which determines the degree of physical fitness. Reduction of the capacity for cardiovascular adaptation to exercise would inevitably be a limiting factor in the consumption of oxygen.

B) Indirect determination of the $\dot{V}O_2$max, the best index of physical fitness, can be based satisfactorily only on tests which establish a definite *relationship between* the $\dot{V}O_2$ max and cardiovascular parameters.

We should therefore consider changes of these parameters in function of exercise.

1. CARDIAC OUTPUT

The cardiac output, Qc is equal to the product of the systolic stroke volume multiplied by the heart rate per unit time.

$$Qc = SV \times HR$$

The resting cardiac output of the healthy adult is between 5 and 7 l/mn. During exercise it may reach 42 l/mn (14), i.e. 6 to 7 times the resting value.

The increase in cardiac output results from increases in both its components:

- systolic stroke volume
- heart rate

- Systolic stroke volume (SV)

The systolic stroke volume at rest of the healthy adult is of the order of 60 to 80 ml. During exercise it may reach 212 ml (14), i.e. about 3 times its initial value.

It would seem that the rise in SV is not a determining *factor for the rise in* cardiac output.

The SV depends on the subject's position, being maximal in the dorsal decubitus position and falls when the subject is upright.

During exercise, the SV is virtually unchanged in decubitus but may rise by up to 40% of its initial value in the upright position.

The increase in VS depends on the extent of energy output, assessed from the $\dot{V}O_2$ max. Up to 40% of $\dot{V}O_2$ max., VS increases linearly but thereafter (40 - 100% of $\dot{V}O_2$ max ) it remains stable (figure 4).

VS is higher in athletic subjects.

Increased VS may occur by two mechanisms which are in fact associated:

- diastolic distension, which increases the stroke ejection volume ( diastolic volume)
- increased contractile force ( systolic volume).

The force of systolic ejection is proportional to the diastolic distension of the myocardial fibre (FRANCK and STARLING's Law).

- Heart rate (HR)

This increases with exercise and in a quasi-linear manner with oxygen consumption (1,17) as can be seen from figure 4.

The maximum heart rate (HR max.) is reached with $\dot{V}O_2$ max., which is near to the stage of exhaustion and discontinuation of the exertion (22).

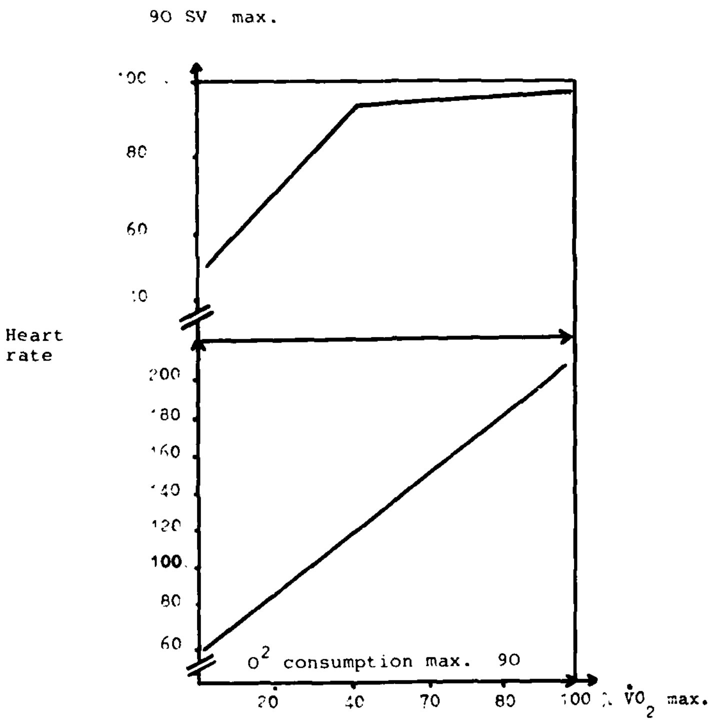



FIGURE 4

Changes of systolic stroke volume (SV) and of heart rate (HR) in function of oxygen consumption ($\dot{V}O_2$) expressed as the percentage of $\dot{V}O_2$ max. (after ASTRAND and RODALL (1)). It can be seen that above 40% of $\dot{V}O_2$, only the HR contributes to the rise in cardiac output. QC = SV x HR.

The maximal heart rate during exercise (HR max) is fairly constant in a population of any given age. It can in practice be expressed as the equation below (12, 10 ):

$$HR\ max. = 200 - age\ \text{(expressed in years)}$$

It has been shown that an HR of 130 is equivalent to 50% of the $\dot{V}O_2$ max.(17-34) This is higher in the subject who has undergone training than in the untrained subject. (figure 5).

In practice, for any given work W, the HR is lower in trained subjects. This results from their greater ability to consume oxygen in the muscles, i.e. their greater physical fitness.

Summary

The increase in cardiac output (Qc) with exertion is more closely related to HR than to SV, which is significantly involved only in effort in the upright position.

Figure 6 (like figure 4) indicates the involvement of SV and HR in the rise of cardiac output during exercise.

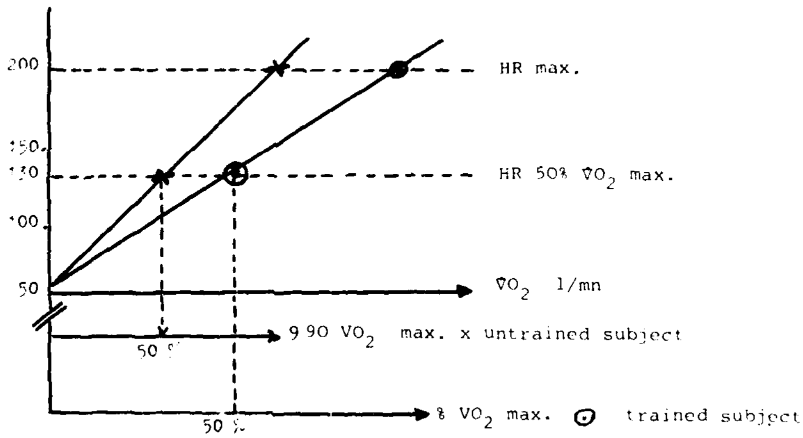



FIGURE 5

Changes in the heart rate in function of the $\dot{V}O_2$ in an untrained subject (x) and in a trained subject ( ) after HENANE et al. (22).

The oxygen consumption capacity is higher in the trained subject than in the untrained subject.

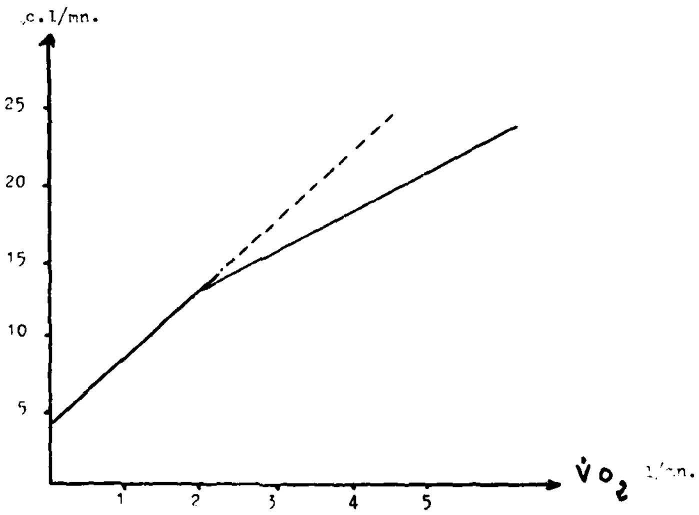



FIGURE 6

Increase in the cardiac output (Qc) in function of the $\dot{V}O_2$ after HENANE et al. (22).

Cardiac output increases linearly to about 40 l/min $\dot{V}O_2$ and then less steeply because of the plateauing of the SV (Cf figure 4).

## 2. ARTERIOVENOUS OXYGEN DIFFERENCE

The transport of oxygenated blood to the muscles is of value only if the muscles are able to extract oxygen from it.

The diffusion of oxygen from the capillaries into the muscle tissue occurs along two concentration gradients:

- the longitudinal concentration gradient along the length of the capillaries from the arteriole to the venule;
- the transverse concentration gradient away from the capillary across the surrounding tissue.

If the partial pressure of oxygen ($PpO_2$) falls, then diffusion is reduced. THEWS has defined a zone of hypo-oxygenation corresponding to capillary $PpO_2$ values too low to allow diffusion to take place and in which the tissues are consequently no longer oxygenated (35). This hypo-oxygenated zone is produced if the capillary $PpO_2$ falls to 17 mm Hg.

During exercise, the blood mass is redistributed into the muscles and extraction of $O_2$ is increased from the muscle capillaries. The venous oxygen is considerably reduced and tissues near the venous pole of the capillary are in a hypo-oxygenated zone (22).

The concentration of $O_2$ in arterial blood is 20ml/120ml and that of venous blood is 5ml/100ml. The arterio venous difference is equivalent to the amount of oxygen extracted by the active tissues.

Very highly trained subjects have a much greater supply of active capillaries in the muscle (400 capillaries per mm2, i.e. virtually one capillary per fibre) than untrained subjects.

In the trained subject, the arterio-venous difference during exercise ranges between 15 and 18 ml of $O_2$ per 100 ml of blood, whereas in the untrained subject it is only 6 to 13 ml. This improved extraction of oxygen by the muscles allows the trained subject to attain a higher $\dot{V}O_2$ max. than the untrained individual and for exercise of a given work output, W to attain it with less cardiac work.

TO CONCLUDE

Muscular exertion can occur only by means of increased oxygen consumption $\dot{V}O_2$.

This is made possible by the mobilisation of the "circulatory reserve" which consists of :

- an increase in cardiac output or cardiac reserve
- an increase in the venous extraction, expressed as the arterio-venous difference (see figure 7).

FIGURE 7

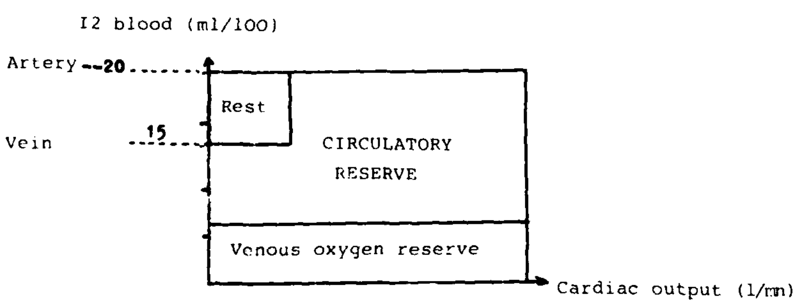



Diagram showing the circulatory reserve after HENANE et al. (22).

The cardiac reserve, assimilated to the cardiac output reserve predominates. It is more dependent on the increase in the heart rate than on that of the systolic stroke volume.

The $\dot{V}O_2$ max. is then largely dependent on the heart's ability to adapt to exercise.

## V - CARDIAC ADAPTATION TO EXERCISE

### 1. CARDIAC WORK AND MYOCARDIAL OXYGEN CONSUMPTION ($M\dot{V}O_2$)

The heart is a muscle with a specific consumption of oxygen ($M\dot{V}O_2$) which increases with exercise.

The myocardium, which works continually, supplies energy during systole and recuperates energy during diastole.

The main factors involved in myocardial oxygen consumption ($M\dot{V}O_2$) are shown below in figure 8:

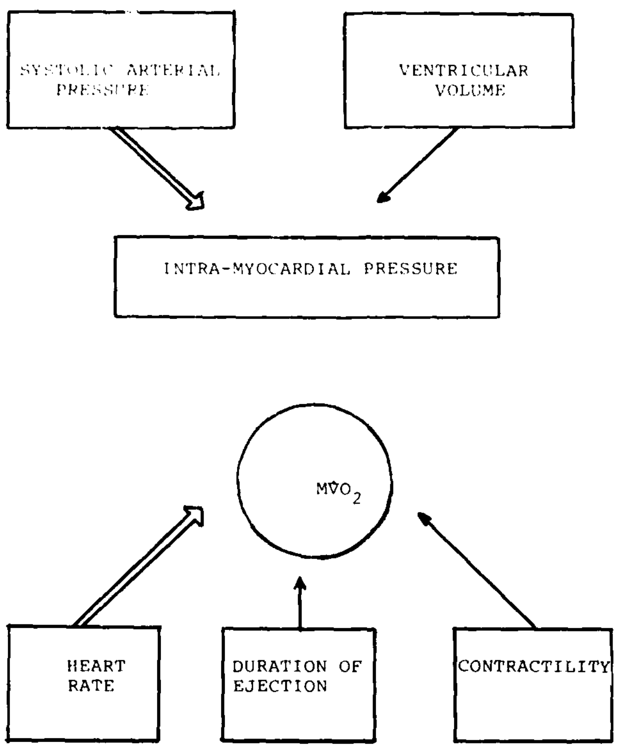



FIGURE 8

The main factors involved in myocardial oxygen consumption ($M\dot{V}O_2$)

- heart rate
- intra-myocardial pressure

The intra-myocardial pressure is, itself influenced by two factors

- the systolic intra-ventricular pressure (in practice determined from the systolic arterial pressure (B.P. )
- the ventricular volume (or, what comes to the same thing in practice, the ventricular radius).

Other important factors involved in the $M\dot{V}O_2$ are:

- the duration of systolic ejection
- the contractility

In practice, the most important factors are as follows:

- heart rate (HR) and systolic arterial pressure (BP);
- the HR x BP product is a good reflexion of cardiac work and $M\dot{V}O_2$ (20-29). (Translator's note : this product is often replaced by ST.T (Systolic time x tension) by British and American authors). This is both the most reliable criterion and the one most widely used even though it does not take into account any of the other factors governing the $M\dot{V}O_2$.

This is true for the subject with coronary artery disease and for the healthy subject.

For a given patient, an attack of angina generally occurs at the same value of the HR x BP product. This value directly expresses the maximum myocardial oxygen consumption ( $M\dot{V}O_2$ max. )

2. CORONARY RESERVE

The concept of circulatory reserve, the supplementary amount of oxygen which the blood is capable of supplying to the tissues, can be applied as already described to the myocardium ( See figure 7).

The CORONARY RESERVE is equal to the product of the coronary flow multiplied by the myocardial arterio-venous difference.

- The arterio-venous difference, index of the myocardial extraction of oxygen, is very great even in the resting subject. The coronary venous blood contains only 3.9 to 6.9 ml of $O_2$ per 100 ml of blood.

During exercise, the myocardial extraction of oxygen, which is already very high, increases only very slightly.

- An increase in coronary flow is then the only way of increasing myocardial oxygenation. In practice then the coronary flow accounts for the coronary reserve.

VI - CONCLUSIONS

Physical fitness, or the capacity for exercise, is related to the capacity of the muscles to use oxygen.

Maximal oxygen consumption ($\dot{V}O_2$) or aerobic capacity is therefore the best overall index of physical fitness.

This is related to the circulatory reserve which in turn involves two essential factors:

- the transport of oxygen to the muscles is virtually the same as the cardiac output;

- the capacity of the muscle to extract oxygen from the blood, as indicated by the arteriovenous difference. Training promotes this extraction by developing the capillary network of the muscles.

The increase in cardiac output, or cardiac reserve, is more closely related to the increase in the heart rate rather than that in systolic stroke volume.

There is a maximal heart rate given by the equation 220 - the age (in years) which corresponds to the $\dot{V}O_2$ max.

The rise in cardiac output increases the cardiac work and oxygen consumption. These can conveniently be assessed by an indirect and rather rough method from the product:

- Heart rate x systolic arterial pressure.

Increase in cardiac work is made possible only if the supply of $O_2$ to the myocardium is sufficient. The potential for increased myocardial oxygenation is dependent on the coronary reserve which, in practice, is related to increased coronary flow, since $O_2$ extraction by the myocardium is very high even at rest.

On this basis, two types of exercise-test have been devised involving the determination of cardiovascular parameters.

1. Exercise tests suitable for the assessment of physical fitness and in monitoring trainees.

2. Exercise tests for diagnostic purposes, intended to detect or evaluate disease conditions, particularly coronary failure.

# PART TWO

## INDICATIONS AND CONTRAINDICATIONS FOR EXERCISE TESTS

### I - INDICATIONS

These correspond to three aims:

- investigatory screening in high risk subjects with no clinical symptoms
- a feature of diagnosis in the examination of a condition, especially of coronary artery disease
- a feature in the assessment of the functional conditions of a patient or of a normal subject or athlete.

### 1. THE CORONARY ARTERY DISEASE PATIENT

This indication, which for a long time was the only interest of teams carrying out exercise tests, remains the major indication at the present time.

Exercise tests occur at various times during the coronary artery disease:

- at the time of diagnosis, in the face of a typical or atypical painful syndrome and in the absence of any progressive phase, the EECG is a key test. It may also be carried out in some subjects presenting a high risk factor and with a particularly dangerous professional post;
- during convalescence after myocardial infarction, the EECG is part of the rehabilitation of the coronary artery disease patient leading to a progressive increase in physical capacity, greater functional tolerance and also in adaptation of treatment;
- after the placing of a shunt, the EECG gives a valuable indication of the functioning of the graft. However a negative test result does not necessarily establish its permeability.

### 2. OTHER INDICATIONS IN DISEASE CONDITIONS

Some minor cardiopathic conditions may also be tested in order to situate the level of tolerance. This is carried out currently in the case of valvulopathies, even of the aorta, which had long been considered as contraindications. For many authors the EECG is an important factor when deciding whether to operate in congenital aortic stenosis. The test can also be used to assess the tolerance of intra-cardiac shunts and primitive myocardiopathies whether obstructive or otherwise.

Hypertension is a recent field for the application of EECG with many possibilities.

In a diagnostic perspective, they can be used to differentiate between labile hypertensive subjects and subjects with normal blood pressure on the one hand and those with permanent hypertension on the other. EECG can also be valuable in pharmacological discussion in order to differentiate the mode of action of the various drugs and to establish their efficacy in unusual conditions.

These tests have also proved valuable in the investigation of arrhythmias since they have been shown to trigger episodes of arrhythmias.

Depending on the type of excitability abnormality, the disorder may be increased or may disappear making possible some assessment of severity and of risk.

In particular, in the coronary artery disease patient, the frequency at which extrasystoles are detected is particularly high.

The EECG is a complementary means which could render the test dangerous.

Therefore patients presenting any of the signs listed below should be excluded from such tests:

- progressive coronary artery disorder whether unstable angina or recent myocardial infarction (the threshold generally selected being three weeks with no complications);

- decompensated cardiac failure of whatever cause;

- a severe obstacle on the left side;

- severe disorders of excitability or conduction (high level block);

- severe rhythmic hypertension;

- pulmonary artery hypertension

The criterion of age is no longer considered an absolute contraindication.

In fact all these pathological circumstances constitute non-indications for this type of test which is intended for patients

- having the same diagnosis
- and whose poor functional tolerance is evident to the attentive observer.

The only debatable point is that of arrhythmias, and in particular of ventricular extrasystoles where early reactions to the test can be used to decide whether to continue with the test or not.

There remains the question of poor indications related to difficulties of assessment of changes of repolarisation, whether because of abnormal left bundle branch depolarization block or pre-excitation syndrome in particular, or whether due to certain forms of medication; digitalis glycosides, amiodorone...

## PART THREE

## BASIC TECHNIQUES OF THE EXERCISE ECG

- INTRODUCTION

There are two types of exercise test which correspond to two different aims:

1) EXERCISE TESTS INTENDED TO DETERMINE PHYSICAL FITNESS

These are used particularly amongst athletes but may also be of value in a military setting: parachutists, combat swimmers, commandos and all combattant personnel.

These tests are based on the determination of the oxygen consumption: $\dot{V}O_2$.

The direct determination of oxygen consumption is difficult to perform and so it is often assessed from determinations of the heart rate HR.

One of the tests frequently proposed (12) consists in having the subject perform for a period of six minutes a sub-maximal exertion of work output W. From the HR, the work output and by using diagrams of the ASTRAND-RYHMING type (2), it is possible to determine the $\dot{V}O_2$ max., which is higher the more successful the subject's training.

In these tests the ECG recording is primarily intended to give an accurate and direct determination of the HR.

2) EFFORT TESTS FOR DIAGNOSTIC PURPOSES

The purpose of these tests is essentially to detect pathological states and if possible to attempt to quantify them. The major diagnosis is that of coronary failure.

In this type of test, an attempt is made to determine the maximal exertion corresponding to the $\dot{V}O_2$ max.

In practice, the subject tested must reach an HR = 220 - age.

We will consider only this type of test.

## I - INVESTIGATION OF THE ELECTRICAL ACTIVITY OF THE HEART

### 1. Problems

- The electrical activity of the heart is investigated during the ECG at rest by means of electrodes sited at standard points.

The peripheral electrodes on the limbs may be placed at any point on the limbs. However the precordial electrodes are placed at accurately defined sites (figure 9).

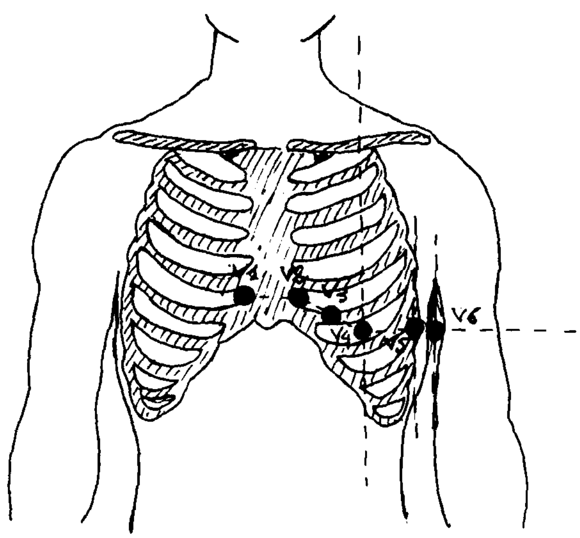



FIGURE 9
Siting of precordial electrodes

VI - Edge of right sternum - 4th right intercostal space
V2 - Left edge of sternum - 4th left intercostal space
V3 - In the centre of the line V2 - V4
V4 - Fifth intercostal space on the medio-clavicular line
V5 - Intersection of the anterior axillary line and the horizontal line through V4
V6 - Intersection of the median axillary line and the horizontal line through V4.

- The determination is difficult not only because of the problems of siting the electrodes but also because of parasite activity. Parasiting of the ECG arises from two main causes:

. parasiting of the ECG recording by an electrical current (50 cycles). This is due to poor isolation of the subject and the instrument (figure 10)

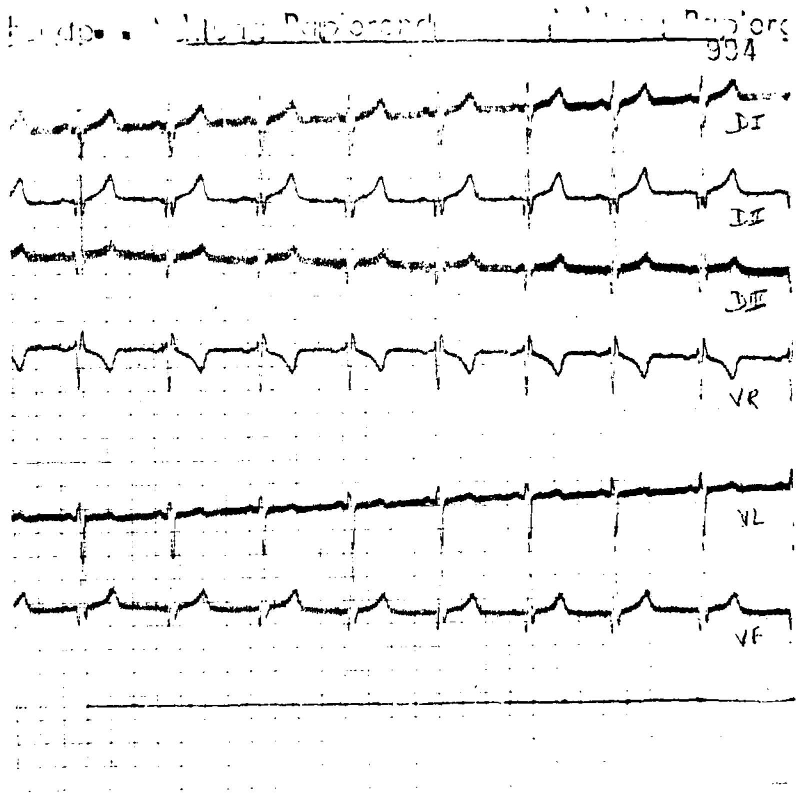



FIGURE 10
ECG parasiting by an electrical current

. parasiting by the myogram due to poor muscular relaxation because of cold, the psychological stress of the examination, etc... (figure 11)

- A third source of difficulty is the need for very close contact between the skin and the electrode. Poor skin-electrode contact is often responsible for an unstable base line (figure 12).

During exercise ECG, these three types of problems are increased:

. the subject tested is standing and not lying down;
. because the subject is moving and not stationary
. because the condition of the skin changes and sweat may be produced

The placing of the electrodes requires very great care if a meaningful recording is to be obtained.

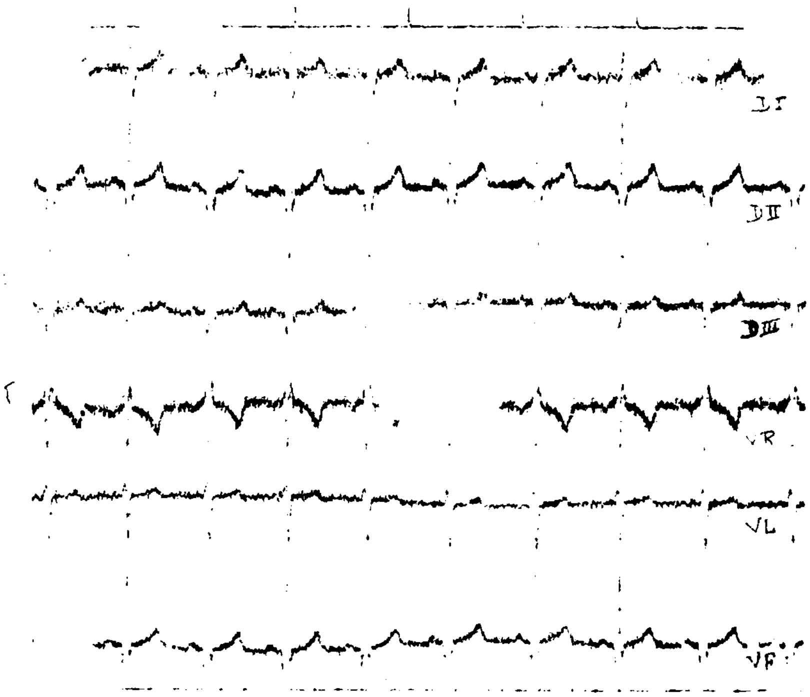



FIGURE 11

ECG parasiting by the myogram

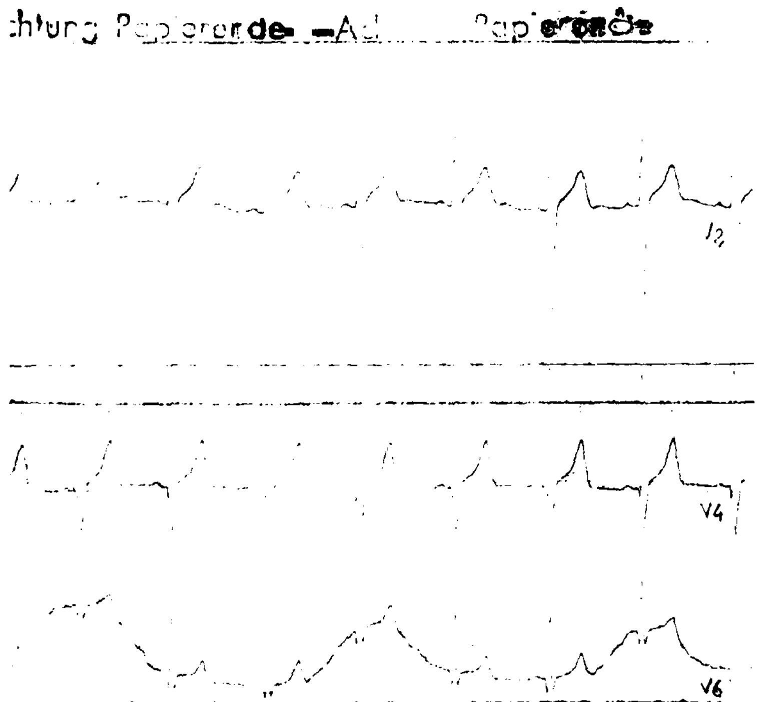



FIGURE 12

Instability of the baseline.

Poor contact of the electrode which is displaced by respiratory movements.

2. Siting of the electrodes

. Peripheral electrodes

The exercise is to involve movement and the contraction of the muscle masses. The peripheral electrodes cannot therefore remain in their usual place at the end of the limbs.

They must be sited where :

- they will undergo little or no movement
- they will not be in contact with the muscle masses

The electrodes on the legs are therefore placed on the sacro-iliac joints or on the anterior-superior spinous processes of the ilium.

The arm electrodes are placed on the acromions, above the shoulder joint, or failing this behind on each side of the cervicodorsal vertebral junction.

. Precordial electrodes

If all leads are to be recorded, the precordial electrodes are placed in their usual position for the resting ECG.

. Bipolar thoracic electrodes

In view of the problems of recording, an attempt has been made to simplify it by reducing the number of electrodes. For this purpose, various systems of bipolar thoracic electrodes have been suggested:

| | | |
|---|---|---|
| V5 | - | V5 R |
| V4 | - | V4 R |
| V4 R | - | V2 |
| V6 | - | V1 |
| V6 | - | Pescador lead |

But the most commonly used assembly is that of the bipolar thoracic electrodes CM 5 = manubrium - V5.

It is made up of the following electrodes:

- peripheral right arm electrode, placed on the sternal manubrium
- peripheral left arm electrode at V5
- peripheral right leg electrode placed on the epigastrium.

The electrocardiograph is placed on D1 during recording

The precordial leads are of special importance during recording of the exercise ECG. However the peripheral leads cannot be dispensed with, especially those which explore the inferior surface of the heart.

3. The electrodes

Traditional electrodes require particularly careful application and attachment to ensure satisfactory contact with the skin during exercise.

Currently, silver-silver chloride electrodes are used, 1 cm in diameter.

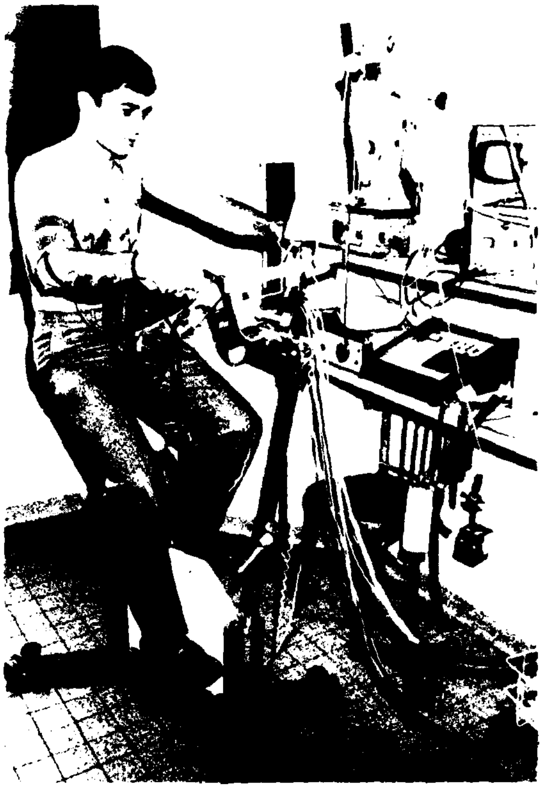
Adherence to the skin is obtained by a self-adhesive disc on both sides.

4. Attachment of the electrodes to the skin

The contact between the electrode and the skin should be as close and stable as possible. This is difficult in the case of the precordial electrodes because of the breathing movements which are very considerable after exercise, and sometimes because of sweat.

In order to overcome these difficulties the skin must be carefully prepared. The skin should be shaved if the hair growth requires it. Any surface grease should then carefully be removed and if necessary the skin scowered. To do this the authors use an abrasive compress soaked in ether. The integument is rubbed vigorously virtually until abrasion of the epidermis, i.e. until fine drops of serum appear.

Modern electrodes and a thin layer of paste provide very good contact. In order to ensure the stability of the electrodes a sticking plaster can be placed over them or they can be held in place by a wide elastic band (see figure 13).



Ergometric bicycle. Note the MSD electrode sited over the acromion and the attachment of the electrodes.

5. The cables

The cables linking the precordial electrodes to the various recording systems may be subjected to pulling and swaying movements during the exercise which may effect the recording.

These movements should be minimised during exercise. In order to do this they should all be attached together. They can also be attached to the thorax at a distance of 10 to 15 cm from the electrode.

6. Recording of cardiovascular parameters

. The electrocardiogram

The ECG is monitored continuously on the screen. It is also recorded on a chart at the normal flow chart rate of 25 mm/sec. The frequence and duration of these recordings varies from author to author. The present authors generally record 10 to 15 seconds from peripheral and precordial leads every minute on a 6-channel recorder. A multi-channel (3 or 6 channels ) recorder is strongly recommended.
The ECG should be recorded at rest, just before exercise, doing exercise and during a 10-minute period following exercise. Abnormal reactions may develop after exercise.

. Blood pressure

The systolic blood pressure is determined about every two minutes using the auscultary method (figure 14).

The systolic pressure is noted at the first audible sound.

The diastolic pressure is more difficult to assess particularly after maximum exercise.

FIGURE 14

Ergometric bicycle and ECG recorder with monitoring screen above

II - FORMS OF EXERCISE

EXERCISE WITH A CONSTANT LOAD AND EXERCISE WITH AN INCREASING LOAD

1) Exercise with constant load or rectangular test

In this type of test the subject immediately reaches the work output required and maintains this load throughout the test until stopping suddenly at the end.

This type of test is particularly suitable for routine use at submaximal effort for the determination of physical fitness.

2) Exercise with rising load or triangular test

This is the method used by clinicians in diagnostic tests. It consists of reaching maximum exertion, corresponding to $\dot{V}O_2$ max., by a series of progressive stages.

Three exercise methods have been used:

a) The MASTER two-step test

The exercise in this test, which is no longer used but which was long considered a reference test, consists of going up and down a set of steps with three rungs (figure 15).

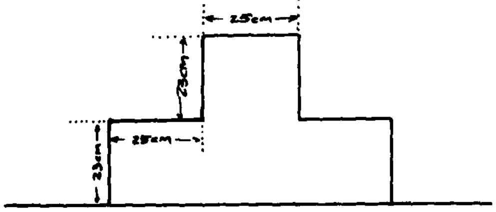



FIGURE 15
Diagram of the Master-step-test steps

The stepping rhythm is fixed by a metronome. The minimum number of steps to be climbed is a function of weight and of age.

The test lasts between 1½ and 3 minutes.

The test is cheap and easy to perform.

However, it is a rectangular test and it is impossible to record the BP during the exercise and difficult to record the ECG.

b) Ergometric bicycle (figures 13 and 14)

This is now the most commonly used method.

1. Principle

The exercise performed by the subject consists in pedalling a bicycle in opposition to an adjustable brake system. The exercise performed depends on the degree of braking and the number of pedal cycles performed during unit time.

In most of the bicycles the number of cycles is set (60 per minute). The work output is increased by raising the resistance of the brake. This obliges the subject tested to follow a constant pedalling rhythm and this is a handicap towards the end of the exercise.

There are two types of brake.

Mechanical brake. This is the simplest brake and consists of an adjustable belt, which opposes the rotation of a wheel driven by the pedalling.

This brake has some technical drawbacks:

. as the belt warms up, it stretches and the actual load of the brake falls;

. the instrument undergoes oscillating movements at very high exertions and is not reliable for maximal tests.

Electro-magnetic brake. This system is both simpler and more complex.

It requires more complex callibration which must be checked regularly. Depending on the type of instrument, the pedalling rate may be fixed (about 60 rpm) or variable.

2. Advantages

The ergometric bicycle has many advantages:

. solidity, reliability, simple maintenance, not cumbersome, simplicity of the test, which does not require practice and so gives good reproducibility;

. the system of signal capture: the electrodes are connected to a box on the handlebar by a relatively short length of cable.

3. Drawbacks

These are mainly related to the muscle masses called into play.

The test has been criticised because it involves only the muscle masses of the legs, which is an artificial form of exercise as compared with that of the treadmill. It should be pointed out that the muscle masses of the legs are those most likely to produce $\dot{V}O_2$ max. which is usually the aim of the test.

However, untrained subjects may be incapable of attaining a theoretical maximum HR equivalent to $\dot{V}O_2$ max. because they are forced to discontinue the test because of cramp or muscular failure of the legs.

At high levels of exertion, when muscle fatigue sets in in the legs, the subjects tested strain against the handlebars with their arm, shoulder and pectoral muscles. The contraction of these muscles parasites the recording.

This can be counteracted by adjusting the saddle height, the subject's position and also by the progressive increase of the exercise level so that as much of the workload as possible falls on the legs.

c) The treadmill

In this test, all the movements involved in walking on a treadmill constitute the muscular work.

Two parameters can be adjusted to increase the workload:

- an increase of the slope of the treadmill, the subject climbs a slope.
- an increase of the speed of the treadmill, this amounts to increased walking speed.

This method is useful for the direct determination of the $\dot{V}O_2$ max., but is less widely used in clinical practice than the ergometric bicycle.

The method has the following drawbacks:

- higher cost, more complex maintenance and more cumbersome apparatus
- more difficult to use, the subject has to have a little practice
- the impossibility of determining the work output directly
- the involvement of all muscle masses, especially towards the end of the exercise, makes ECG recording difficult.

## III - PRACTICAL FEATURES OF THE EXERCISE ECG

We will consider the exercise tests most widely used in clinical practice, the triangular test on the ergometric bicycle.

### 1. Preparation and condition of the subject

- The subject to be tested should be fasting and have abstained from smoking for two hours.
- The subject should have emptied the bladder before the test.
- The temperature and humidity in the examining room should be suitable for exercise. The room should be aired between tests.

  The temperature should not be too high, so as to minimize sweating and slipping of the electrodes. However, too cold a room may produce shivering and muscular parasiting at the beginning of the test.

- The test can theoretically be performed in two positions, either lying or sitting

  . The dorsal decubitus position has some theoretical advantages:

    . better immobilisation of the thorax and shoulders and hence better attachment of the electrodes

    . a physiological advantage, since the systolic stroke volume is maximal when the subject is lying down

    . however, maximal exertion is more difficult to attain in this unnatural position.

  . The seated position is more natural in that it is closer to the usual conditions of exercise and it permits greater work output.

  In practice the seated position is used.

The height of the saddle must be carefully adjusted. The subject must be correctly seated when pedalling so that the pelvic girdle remains stable and the effort is spread over the whole leg.

To achieve this we recommend a rather low position of the saddle which permits full extension of the leg without hip movement. The feet should be held in place on the pedals.

The subject should be instructed to pedal with the shoulders low down, without contraction of the muscles of the shoulder girdle or straining of the arms.

It is important to encourage the subject and to explain the test procedure fully.

### 2. The work load

The subject tested should reach an exercise level equivalent to $\dot{V}O_2$ max. This is assessed from the maximal theoretical heart rate (MTR) calculated from the formula 220 - age in years (Cf. physiological bases).

- The initial level of exercise varies from subject to subject depending on the clinical background.
- For an elderly patient complaining of chest pain, the initial workload should be low, less than 50 watts.
- For a young, asymptomatic and trained subject the initial workload can be over 100 watts.

- The workload is progressively increased by steps, two parameters of which can be adjusted:

  . the increase in workload to the next level (in watts),
  . the duration at each level (in minutes).

Most authors increase the workload by 30 watts every three minutes (WHO recommendations).

The authors prefer an increase of 20 watts every two minutes. In this case the increase in work is much nearer to linear and better tolerated. This is particularly true at the end of the test when an excessive rise of 40 or even 30 watts may result in a sudden discontinuation of the test before the MTR is reached.

Performed in this way, the test does not take any longer to carry out.

In general, what matters is to avoid increasing the workload before the heart rate has stabilised. With increases of 20 watts, the HR generally rises over the first minute and stabilises during the next minute.

## IV - DISCONTINUATION OF THE EXERCISE

### 1. Modalities

When the patient abruptly discontinues maximal exercise, he/she may sometimes present the following signs : palor, sweating, sudden bradycardia (80-60), sudden fall of the BP by 60 - 100 mm Hg, and in particular lipothymia which obliges the subject to lie down.

These symptoms are interpreted as reflecting vagal rebound after exercise and can be prevented by asking the patient to continue pedalling for a minute or two during which time the brake load is rapidly released.

However, if the resistance of the cardiovascular system to exercise is to be assessed, it may be helpful to end the exercise abruptly.

### 2. Criteria

The end of the exercise may have several causes.

2.1 The test may be completed if the MTR (220 - age) has been reached.

2.2 Discontinuation may be due to muscle failure of the legs or to exhaustion without reaching the MTR

2.3 The onset of chest pain. Only typical angina or an atypical episode accompanied by ECG signs of coronary failure should lead to discontinuation of the exercise.

2.4 Abnormal blood pressure parameters:
  . The systolic blood pressure reaches about 200 $\pm$ 20 mm/Hg
  . An excessive rise in BP is a criterion for discontinuation. The threshold which should not be exceeded depends on the age and cardiovascular history of the patient.
  . For a subject of less than 40 years of age with no past history of cardiovascular problems, the BP can be allowed to rise to 300 mm.Hg. *In practice we rarely exceed a value of 260 mm.Hg*
  . In contrast, a fall in BP after an initial rise, should lead to the suspicion of sudden haemodynamic failure and should lead to discontinuation of the test.
  . An absence of any rise in pressure at the beginning of the test should lead to great caution.

2.5 Discontinuation because of severe dyspnoea which is disproportionate with the exercise or because of functional disorders: lipothymia, sweating, palor, etc...

2.6 Arrhythmias

  - The onset of proxysmal arrhythmias (whether atrial or ventricular), should result in discontinuation of the test.
  - Atrial extrasystoles are usually compatible with continuation of the exercise.
  - Only ventricular extrasystoles (VES) cause a problem. Polymorphic VES, those variously coupled or those coupled but with a risk of R/T phenomenon should lead to discontinuation of the test.

- Salvos: doublets, triplets, etc... are an absolute cause of discontinuation.
- The VES threshold is debatable. Some authors suggest discontinuing the tests if the level of VES reaches 10%. In practice, we ourselves have fairly frequently registered much higher levels at the beginning of the test, with the VES incidence falling and even disappearing as the heart rate rises. Any regular rise in the number of VES with increasing exercise should lead to discontinuation of the test.
- For VES as for BP, the clinical background must be taken into account.
- This is also true of bi-geminy and tri-geminy which we do not consider absolute criteria for discontinuation.

2.7 Conduction disorders

- *Atrioventricular block of any degree should result in discontinuation.*
- Right bundle branch block should not lead to interruption unless there is pre-existent left hemiblock.
- Left bundle branch block is not theoretically a criterion for interruption, but should give rise to caution.

2.8 Primary repolarisation disturbances

- Abnormalities of the T wave. It is usual to register large T waves during exercise.
- The appearance of an isolated inversion, particularly if it occurs early on, should not lead to discontinuing the test. It may be related to hyper-ventilation. This may be confirmed by carrying out a resting ECG during hyper-ventilation (figure 16).
- ST-segment abnormalities. Upward or downward shifts of the ST segment are signs of coronary failure. They result in interruption of exercise (Cf. Part V: coronary failure).

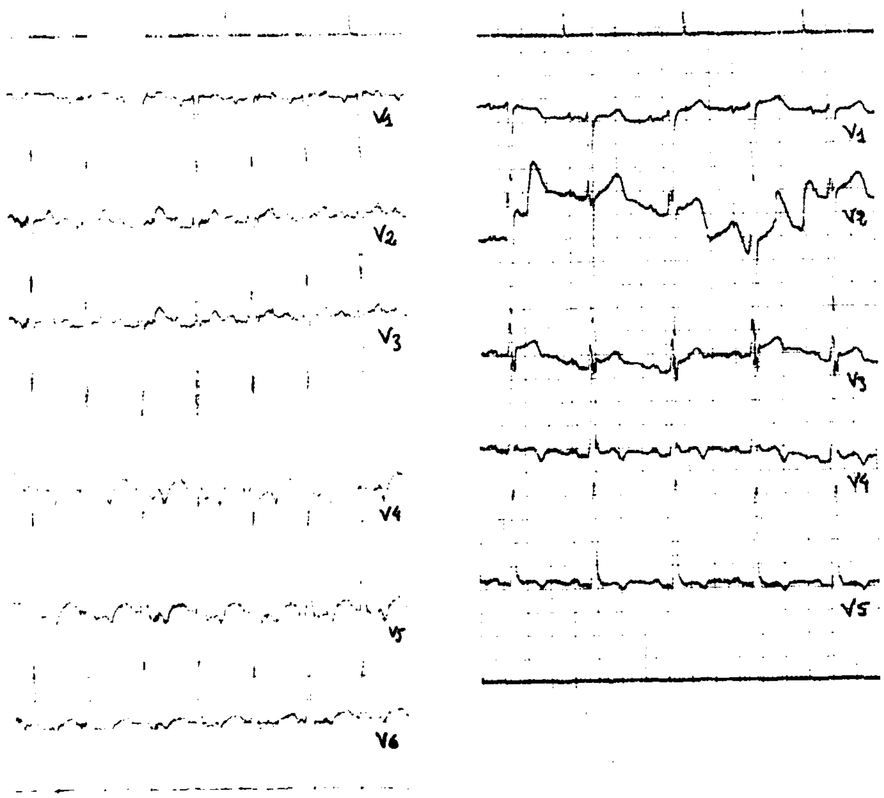



FIGURE 16

PAZ - helicopter pilot 38 years

On the left: EECG
On the right: Hyperventilation Test

# PART IV

## THE NORMAL EXERCISE ELECTROCARDIOGRAM (EECG)

Exercise produces modifications of the ECG recording even in the absence of any disease factor.

### I - MODIFICATIONS OF THE ECG DURING EXERCISE

It is essential that these modifications be understood if the EECG is to be interpreted correctly. They include the following:

1° Sinus tachycardia which increases regularly and in proportion to the exercise.

2° An increase in the P amplitude, particularly on DII - DIII. However the P wave does not exceed 3 mm.

3° A shortening of the PR interval, which is generally in function of tachycardia and slight (0.01 - 0.02 s). If there is an initial functional lengthening of the PR interval of vagal origin, it shortens and becomes normal as soon as exercise begins.

4° Sloping of PQ and lowering of J (figure 17). This is one of the most usual changes in the ECG and is due to an increase of the negative BP atrial repolarisation, which normally passes unnoticed, masked by the QRS complex (25).
J may be depressed by 1 to 2 mm or even more. This depression is partly conditionned by instability of the isoelectric line. The depression of J in isolation is therefore a physiological phenomenon which produces the junctional pattern.

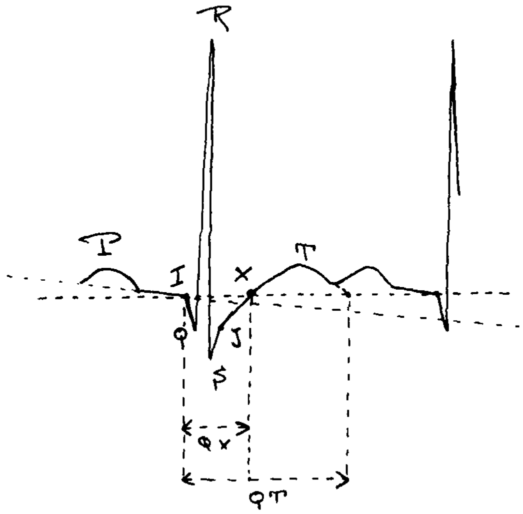



FIGURE 17

EECG Modifications (healthy subject)
Functional aspect.

5° Various changes of the T wave may occur. The amplitude of the wave usually decreases (2/3 of cases) but may increase (1/3 of cases). The T wave changes in function of exercise and of oxygen consumption, but also of other parameters such as hyperventilation (figure 16).

6° Various changes are also possible in the U wave. However the wave should not be inverted. In high frequency tachycardia, the T, U and P waves are telescoped and become very difficult to distinguish or interpret.

## II - DETERMINATION OF THE ISOELECTRIC LINE

Much of the analysis and interpretation of the EECG is based on assessment of the shift of the ST segment relative to the isoelectric line. The extent and duration of such shifts are more readily determined the better the recording and in particular the better the isoelectric line.

At the end of the test, when maximal exertion is reached, the isoelectric line may become unstable and waver. This results in artificial shift of J and of ST which make the recording uninterpretable. A depressed phase in the isoelectric line tends to exaggerate any downward shift, whereas an elevated phase tends to reduce or obliterate it.

In practice, in order to assess the recording correctly, we look for a series of at least three complexes aligned on the isoelectric line and we interpret the central complex. The isoelectric line is then defined by the straight line passing through the points I at the beginning of the QRS complexes (figure 17). To avoid being hindered by fluctuations in the recording, EPESCHKIN suggested measuring the shifts of ST relative to the straight line prolonging the PQ segment (figure 17). In practice this is not always easy, particularly when the test becomes maximal. Some instruments are able to evaluate the slope of the ST segments and this is a big step forward (Cf. Part V-1-3).

## III - QX AND QT INTERVALS

Two intervals are frequently defined and used in the EECG.

- QX Interval

  This begins at the beginning of the Q wave (Point I) and ends at the intersection between the isoelectric line and the ECG record, when this crosses it as it rises after point J (figure 17).

- QT Interval

  This begins at the beginning of the Q wave (point J) and ends at the end of the T wave or of its projection when this is merged with T (figure 17)

In the healthy subject QT/QX is greater than 1, i.e. QX is less than XT.

# PART V

## THE EXERCISE ELECTROCARDIOGRAM (EECG) IN CORONARY FAILURE

In the normal physiological state there is a balance between the myocardial consumption of oxygen ($M\dot{V}O_2$) and the coronary flow.

If this balance is destroyed because the coronary supply of oxygen is insufficient myocardial ischaemia appears.

The EECG attempts to provoke and demonstrate this phenomenon.

A reduction of 50% in the diameter of the coronary artery lumen is thought to be necessary for its occurrence.

- Myocardial ischaemia has four consequences:

- metabolic consequence - release of lactates
- ECG consequence - ST segment shift
- haemodynamic consequence - modified ventricular function
- clinical consequence - onset of angina pain

The highest intra-myocardial systolic pressure occurs at the sub-endocardial region. It is therefore this region which is the first to suffer if hypoxia occurs. This sub-endocardial stress is reflected in the ECG by a downward shift of the ST segment. This downward shift of the ST segment is therefore the most characteristic and general ECG sign of coronary failure.

In some cases, an upward shift of ST may occur which is interpreted as a sign of transmural myocardial stress which is more serious.

The ECG modifications precede the onset of pain.

Before describing EECG changes seen during coronary failure we should make a preliminary remark.

The diagnostic value of the exercise ECG was established on the basis of coronary angiography.

However coronary angiography has its own limits and errors. Furthermore since most of the EECG-coronary angiography correlations were performed, the concept of coronary artery spasm, intermittent functional stenoses, have been developed and these can be detected only by pharmacodynamic tests.

This amounts to saying that the EECG has limited value as a diagnostic tool for coronary failure.

## I - MODIFICATIONS OF THE EECG IN CORONARY FAILURE

### 1. Downward shift of ST

Ischaemic aspect (figure 18)

This is considered the most important aspect of coronary failure.

It is characterised by the following features:

- a depression of at least 1 mm of point J
- a downward shift of the T segment, also of at least 1 mm, the segment being horizontal or slightly downward sloping towards the right for at least 0.08 m.
- a jagged ST.T function forming a clear angle
- a delayed return to the isoelectric line with QS greater than XT.

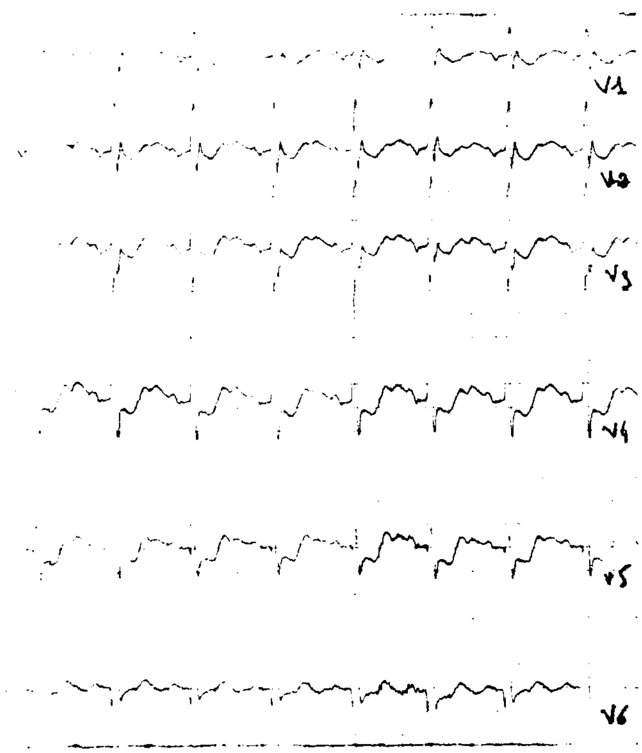



FIGURE 18

VAL 51 years - typical severe angina. Ischaemic pattern.

- Variant pattern (figure 19)

This is very similar to the previous pattern. The criteria are the same. In addition, the ST segment is clearly descending and presents an upward convexity. This is also highly significative of coronary failure.

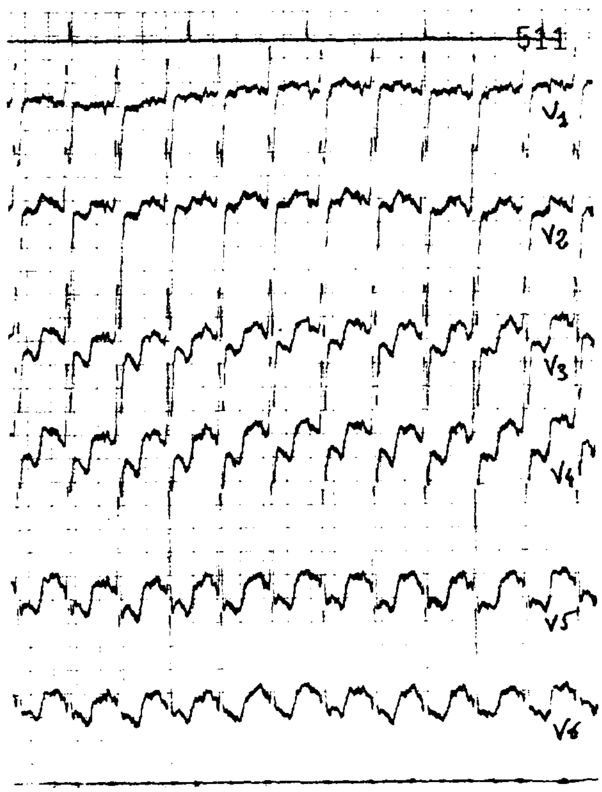



FIGURE 19

DANT 40 years - Angina
Variant pattern

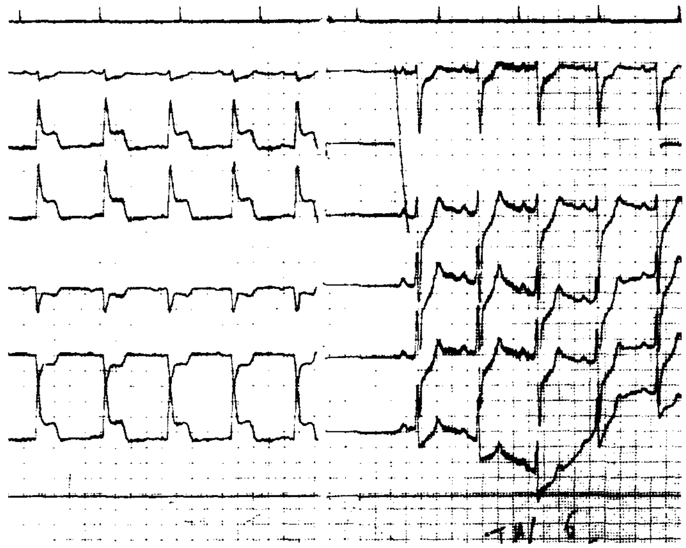
2. Elevation of ST (figure 20)

This pattern is defined by an elevation of point J by at least 1 mm, followed by an elevated ST segment which may be horizontal or have an upward convexity. The diagnostic value of such a pattern is great but it is rarely encountered.

- during exercise in subjects with an ECG also presenting a necrotic Q wave, the presence of an elevated ST often reflects ventricular dyskinesia;

- depression of ST can also be detected during angina despite healthy coronary arteries, which is similar to the ECG pattern of Prinzmetal angina, but which develops during exercise.

With the exception of the elevation of the ST, only the ischaemic (or variant) type of ST elevation is an EECG abnormality signifying coronary artery abnormality detectable by coronary angiography. However other EECG modifications lead to the suspicion if not certainty of such coronary artery disease. These are modifications of the QRS complex, the T wave or the U wave (6).



LA... 23.02.78 minute 5 72/mn

FIGURE 20

LAL - Effort angina
- Elevation of the ST segment on discontinuation of exercise
- Normal coronary angiography

Transitory necrotic appearance

During an EECG a Q wave suggestive of necrosis may occur which disappears rapidly when exercise ceases.

Such a phenomenon has not yet been fully explained. Its significance remains unclear (figure 21).

3. Modifications of T

Inversion of the T wave in isolation does not imply coronary disease.

However MASTERS (27) after many years of experience has some reserves concerning T modifications.

He would consider the isolated inversion of the T wave of at least 1.5 mm suspicious if the T wave was already initially positive (or negative) to at least 1.5 mm.

Currently any clear inversions of the T wave or major increases in its amplitude remain suspicious but not positively diagnostic.

4. U wave modifications

More significance is given to the inversion of a U wave (15). Some authors also insist on its resto ration by means of nitroglycerine (6).

In practice, at the degree of tachycardia where such modifications of EECG generally occur, it is fairly difficult to identify the U wave correctly.

II - THE DIAGNOSTIC VALUE OF THE EECG IN CORONARY FAILURE

After carrying out an EECG in order to diagnose possible coronary failure, the test is generally assessed as either positive or negative. This simply implies that criteria considered to signify the presence of lesions detectable by coronary angiography has been detected on the EECG.

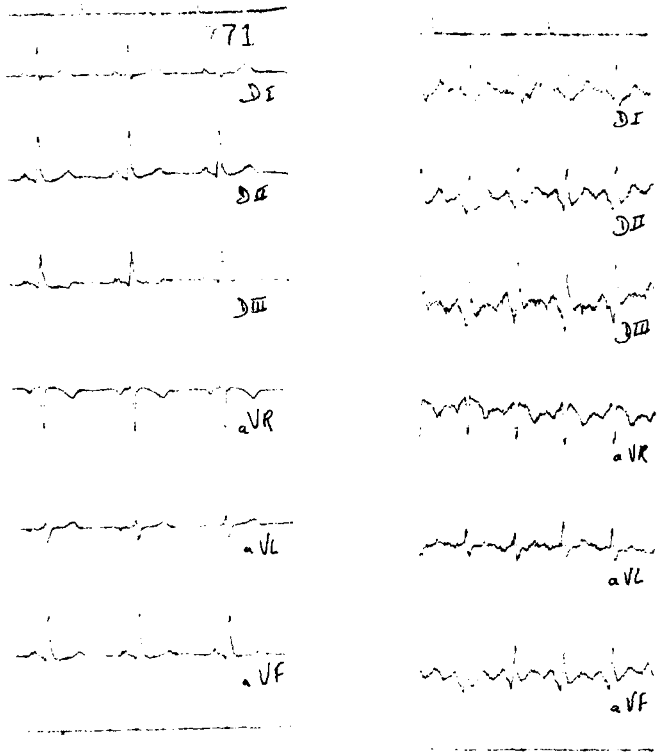



FIGURE 21

DEN, 36 years - Angina
Left: before exercise Right: after exercise
Q wave on posterior leads.

Comparison of the EECG - coronary angiography have demonstrated that false positive EECGs do exist, i.e. which present ECG criteria of coronary artery disease even though the angiography is normal. False negative EECG also exist where the coronary angiography shows abnormality.

The frequency of such false findings depends above all on the severity of the ECG criteria selected.

It also depends on the clinical and epidemiological background of the subject.

We will therefore consider the various parameters to be taken into account in EECG even though we are aware that this test cannot give certainty as to the presence or absence of coronary artery lesions but simply an indication of a probability which in some cases may approach 100% .

1. Intensity of exertion

Only maximal tests can be taken into consideration, i.e. those in which the subject under test attains about 100% of the maximum theoretical rate (MTR). The risk of false negative findings rise as this percentage falls.

In practice the only test to have any significance is one in which the heart rate reaches 90 to 100% of the MTR . Below 85% a negative test is devoid of significance.

The criteria of a positive test may obviously appear below the MTR.

However the appearance of a depressed ST in an asymptomatic subject (no chest pain) undergoing an expert clinical examination should not result in discontinuation of the test unless the depression becomes considerable (above 3mm).

We have seen apparently significant depressions disappear at the end of the test as the MTR was reached. In such cases the coronary angiography was normal (figure 22).

In the authors' experience, the onset of chest pain in the absence of ECG modifications does not preclude continuing the tests.

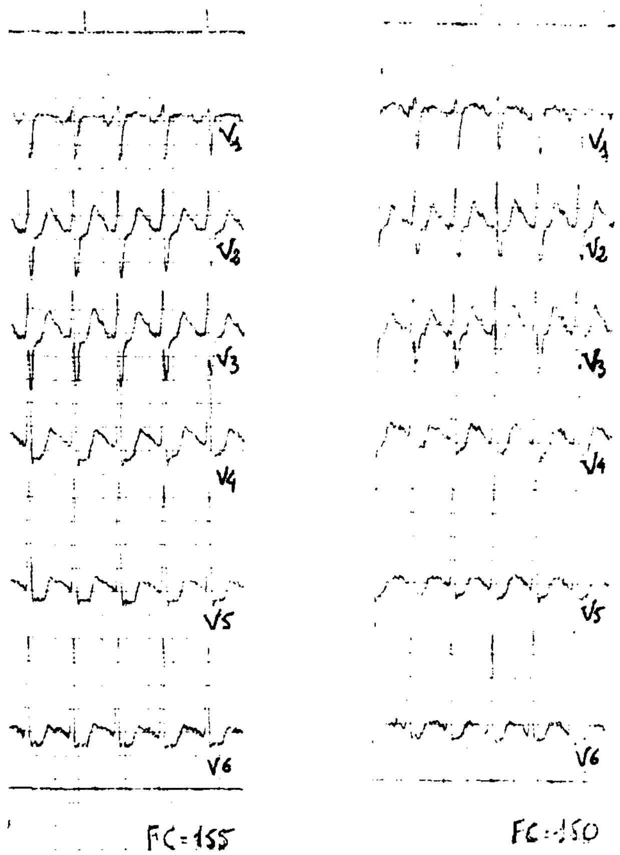



FIGURE 22

GAR, 41 years, pilot - EECG

- Left hand side: significant ST depression between V4 and V6
  HR = 155
- Right hand side: non significant functional pattern
  HR = 180
  Normal coronary angiography

## 2. Detection of the signal

EECG reliability increases the better the cardiac activity is detected. The selection of leads is therefore important. BLACKBURN et al (4) have established that all modifications of ST and T which appear during exercise can be detected in 6 of the 12 standard leads.

These leads are as follows: DI - DII - VF - V4 - V5 - V6.

These authors have also established the percentage of positive findings in function of the leads selected (figure 23).

| LEADS | PERCENTAGE OF POSITIVE RESULTS |
|---|---|
| V5 | 89% |
| V6 | 91% |
| V4 + V5 + V6 | 93% |
| V3 + V4 + V5 + V6 | 94% |
| DII + V3 + V4 + V5 + V6 | 96% |
| DII + a VF + V3 + V4 + V5 + V6 | 100% |

FIGURE 23

Exercise ECG sensitivity in function of the leads selected (after BLACKBURN)

The CM 5 lead was the most sensitive to ST depression but gave 4% of false positives.

BLACKBURN (4) recorded modified ST on D2 - D3 - VF in 30% of subjects presenting an ischaemic type response to exercise. In 7% of these cases,the ST modifications were localised in the posterior peripheral leads.

3. Severity of the electrocardiographic criteria - The problem of "intermediate" patterns

Depending on the threshold fixed for the electrocardiographic criteria of coronary failure, they will be more or less false negatives or false positives.

If these criteria are very rigorous, (e.g. an ST depression equal to at least 3mm ) there will be virtually no false positive but one runs the risk of false negatives.

If on the other hand the criteria for a positive test are less severe (e.g. an ST depression of 0.5 mm) there will be many more false positives.

There is general agreement to fix the criterion for a positive test as an ST depression of at least 1 mm lasting for at least 0.08 sec.

However, the appearance of the ST segment is not defined in this criterion particularly whether it is horizontal, ascending or descending. This results in some statistical disagreements on the diagnostic value of the EECG.

The significance of the T segment is discussed on the basis of some functional aspects.

The functional pattern is characterised by a depression of point J of at least 1 mm followed by a rising ST segment (figure 24). This may be difficult to interpret because this description in fact covers various patterns.

Point J can be followed by an ST segment which rises steeply immediately, the junction with the T wave occurs with no angulation, the QX segment is short, with QX less than QT. This would be a physiological pattern frequently recorded during exercise (figures 17 and 24).

Point J may be followed by a more rigid ST segment which rises more slowly. The ST-T junction is angular and the QX segment longer, with QX greater than XT.

A pattern of this type may correspond with normal coronary angiograph images (figure 25), or with significant atheroma coronary artery stenoses (figure 26).

As early as 1928 KASSEBAUM et al. (24) drew attention to the difficulty of interpreting these patterns.

In a group of 39 subjects presenting clearly pathological coronary angiographs, these authors obtained "functional" type ECG recordings in 14 cases.

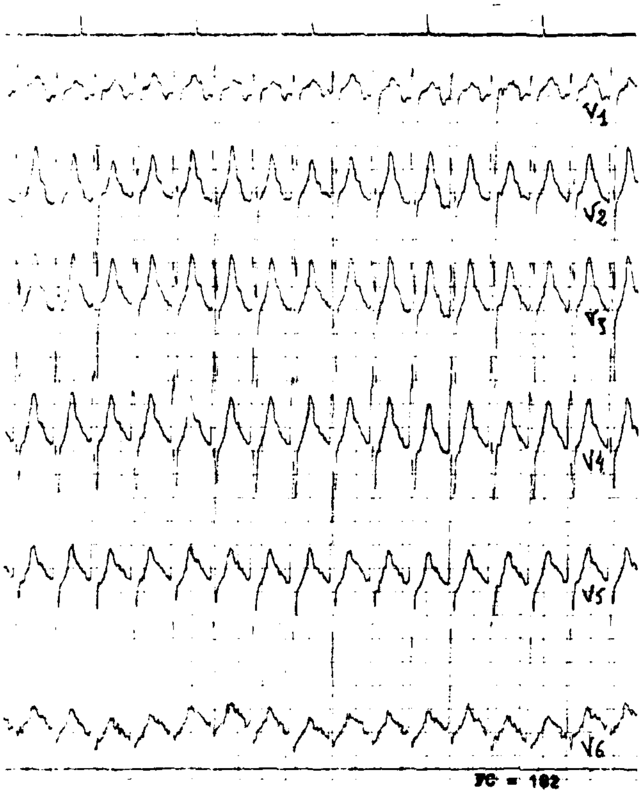



FIGURE 24

BAC, 20 years, athlete
Normal EECG

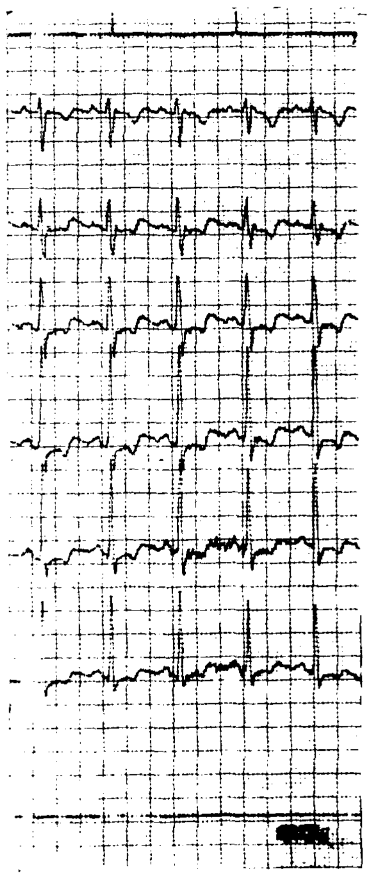


FIGURE 25

STI, 36 years, fighter
pilot
EECG
Normal coronary
angiograph.

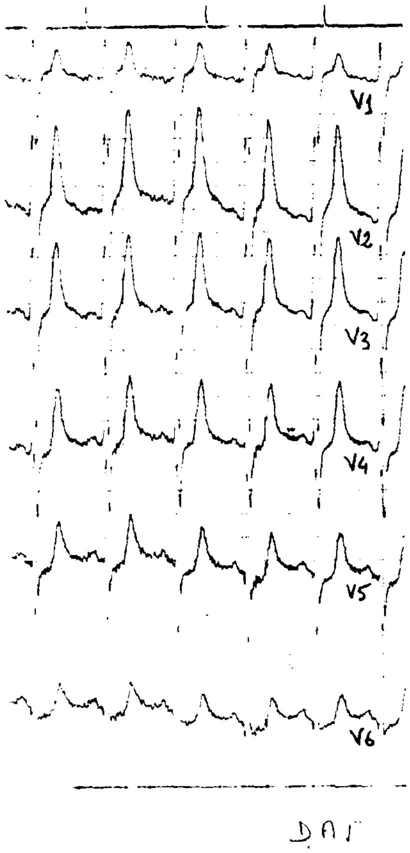



FIGURE 26

DAT, 39 years,
Effort angina

EECG
Coronary angiograph
- 2 stenoses in
excess of 50% .

In another group of 28 subjects presenting normal coronary angiograph, the same functional pattern was detected in one case out of two.

The authors also raised the question of false positive and false negative tests, but it remains true that the term "functional pattern" is sometimes used to describe clearly differing ECG recordings.

MASTER (27) had already described a "near ischemic J depression type" pattern which also stresses the variety of recordings which are in fact classified as functional. He stressed the negative significance of the <u>straightness and lengthening of the ST segment</u>.

It is certain that the assessment of such recordings does affect the value of the method and the number of false positives or false negatives.

The interpretation of these "intermediate" patterns can be improved by an investigation of the slope of ST. For this purpose some recorders are equipped with an automatic graph analysis system not only of the ST shift but also of the slope.

The ST slope provides a more detailed analysis of the ECG recording particularly if the base line is not isoelectric. Changes in the ST slope appear to have greater significance in the diagnosis of coronary failure than ST shifts (23).

In usual practice as well as the numerical criteria :

- Depression of 1 mm

- Duration of 0.08 s.,

the form of the ST segment, whether it is horizontal or descending, whether it is rigid or lengthened are also of importance in its interpretation.

4. <u>Time sequence</u>

ST modifications (depression) may be detected either only during exercise, or else during exercise and during the first few minutes of rest following exercise or else only after the end of exercise.

Usually the ST depression occurs during exercise.

The prolongation of ST depression after the discontinuation of exercise, but which had occurred during exercise, is generally accepted as an additional criterion for a positive test, and may be a useful criterion in the assessment of the severity of the disease.

ST modifications occuring after the exercise are more controversial. This pattern is related to a clearly abnormal coronary arteriograph.

In 1967, MASON et al (26) in a group of 56 coronary artery disease patients, presenting typical angina, and pathological coronary angiograph, detected significant depression of ST (in excess of 1 mm) at the time indicated below:

- Positive EECG during exercise only ................6 cases
- Positive EECG after exercise only ................23 cases
- Positive EECG both during and after exercise ......27 cases

If the EECG became positive after exercise, the depression tended to appear about two minutes after halting the test and not immediately.

However any modification of the ECG occurring more than 4 Minutes after the end of exercise would seem to be without significance.

Many authors haves stressed the greater specificity of ST depression after exercise. For BLACKBURN in particular the post-exercise pattern is more significant than that determined during the exercise.

However some authors including CHAING(9), and GUTMAN (21) have reported the onset of ST depression of at least 1mm after exercise in 7% of normal subjects. It should be pointed out that this was in treadmill tests restricted to two millimeters in 1 group (21) and monitored by angiograph.

SERRA-DIMIGNI (33) and BELET (3) found an abnormal response only during exercise.

1.' SUMMARY

The best EECG criteria of coronary failure are as follows:

- maximal exercise test (HR = 220 - age)

- recording on at least 6 leads (DI - DII - VF - V4 - V5 - V6)

- depression of ST by greater than or equal to 1 mm, for at least 0.08 s.

  . on condition that ST is either horizontal or descending
  . the ST.T junction has a definite bend
  . $\frac{QX}{QT}$ is greater than 0.5 - (QX greater than QT)

- continued depression after discontinuation of exercise

The elevated ST is also a highly positive indication.

5. <u>Epidemiological and statistical importance of the EECG</u>

The diagnostic significance of the EECG for coronary failure depends on the population considered. This fact must be borne in mind when interpreting results.

A test yielding positive findings suggestive of coronary failure establishes only the probability of significant coronary artery lesions. The level of probability established varies widely from population to population.

It may be helpful to give some definitions:

- <u>Sensitivity</u>

This is defined as the ratio

$$\frac{\text{TRUE POSITIVES}}{\text{TRUE POSITIVES} + \text{FALSE NEGATIVES}}$$

and is the proportion of subjects in a given population affected by coronary artery disease (abnormal coronary angiograph) actually detected by EECG.

- Specificity

This is defined as the ratio

$$\frac{\text{TRUE NEGATIVES}}{\text{TRUE NEGATIVES} + \text{FALSE POSITIVES}}$$

and is the proportion of subjects in a healthy population which are correctly identified as such by EECG.

The higher the level of false positives, the lower the specificity.

- Diagnostic value of a positive test

This is defined as the ratio

$$\frac{\text{TRUE POSITIVES}}{\text{TRUE POSITIVES} + \text{FALSE POSITIVES}}$$

and is the probability of the absence of coronary artery lesions if the EECG is positive.

- Diagnostic value of a negative test

This is defined as the ratio

$$\frac{\text{TRUE NEGATIVES}}{\text{TRUE NEGATIVES} + \text{FALSE NEGATIVES}}$$

and is the probability of the absence of coronary artery lesions if the EECG is normal.

Sensitivity, specificity and diagnostic value of the EECG vary from population to population.

In a high risk population (e.g. subjects of over 50 years of age presenting chest pains) the sensitivity and the diagnostic value are very high.

The sensitivity is of the order of 70 to 80% and the specificity of 85%.

In a low risk population (e.g. asymptomatic subjects aged less than 45 years), however, the specificity is poor. This implies that there will be a high incidence of false positives.

This is true for example of a population such as that constituted by aeronautic flying personnel as has been shown by FROELICHER (19). This author carried out a maximal exercise test in asymptomatic US airforce personnel, who presented minor coronary repolarisation disorders. All subjects were excluded who presented any clinical history suggesting angina, infarction or myocarditis and also any subjects presenting a pre-excitation syndrome, any saltwater balance problem etc...

- 60% presented a normal exercise ECG
- 40% (= 76 cases) presented an EECG classified as positive
  These 76 cases underwent coronary angiography
- 33 (= 43%) presented coronary stenosis greater than or equal to 50% (true positives)
- 36 (= 47%) presented healthy coronaries (false positives)
- 7 (= 10%) presented an insignificant stenosis (less than 50%)

In a population of young and asymptomatic subjects the diagnostic value of the EECG would therefore seem to be slight. There is a high risk of false positives = virtually 50%.

The test cannot be applied routinely. It should be limited to high risk subjects. This risk may be medical in nature, assessed on the basis of high risk factors established by the FRAMINGHAM enquiry (high blood cholesterol, smoking, hypertension, etc..)

In some cases the risk may be occupational (cosmonauts, pilots of very high performance aircraft etc...). In this case, interpretation becomes difficult and the risk of error lies rather in false positives than false negatives.

- The female population

The EECG/coronary angiography correlation is less good in women that in men. The false positive level is generally of the order of 25 to 30%.

IN CONCLUSION

The EECG should not be interpreted in isolation.

Initially any positive criteria should be assessed in detail.

Then the test should be situated against the clinical and epidemiological context of the patient (age, symptoms, risk factors ...etc.)

Only in this way can rational use be made of the EECG in the diagnosis of coronary failure.

## III - ECG CRITERIA FOR THE SEVERITY OF CORONARY FAILURE

There have been efforts to improve the interpretation of the EECG by identifying criteria which could serve as an index of the severity of the coronary artery damage.

1. Timing of the ST depression

An early depression is thought to be an index of severity.

In practice as we shall see, the product of the systolic BP x HR is more often used than the timing itself.

2. Extent of ST depression

The greater the extent of the depression of ST, the higher the probability of stenosis. On the other hand the extent of depression is no indication of the extent of the lesion (13).

3. Location of ST depression

ST depression is more often detected on left precordial leads (V4, V5, V6) than on posterior leads.

It has been established that there is no correlation between the location of electrocardiographic disorders and the location of lesions detected by coronary angiography.

However, the diffusion of ECG abnormalities, especially of precordial abnormalities, would seem to be an index of the severity of coronary damage. If associated with a low BP x HR product, this leads to a suspicion of lesions (widespread or proximal (30).

4. Amplitude of the R wave (7-8)

The amplitude of the R wave is increased during exercise in coronary patients.

Various indices of severity could be envisaged based on R modifications.

- increased R wave on V5 during or following exertion,
- comparison between the increase of the R wave on V5 and the depression of ST,
- increase of the sum of R wave on aVL, aVF, V3, V6.

In the healthy subject however there is a fall in the amplitude of R.

This is explained by a simultaneous fall in systolic and diastolic stroke volumes during exercise, whereas the volume of the ischaemic ventricle does not decrease.

It is sometimes difficult to assess changes in amplitude of the R wave especially towards the end of exertion when respiratory movements are exaggerated.

The mean of 20 complexes should be taken.

The increase in R wave amplitude is an index of severity which is detected particularly if there are ventricular repercussions of coronary failure.

5. HR x BP product (more commonly represented by ST.T)

The product of the heart rate (HR) x the systolic blood pressure (BP) is a good index of the $M\dot{V}O_2$ (see the Section Physiological bases of the EECG).

The HR x BP product is more often expressed as ST.T (Systolic tension Time Index). This product would appear to be a useful criterion of severity and provides confirmation of a positive test.

- An HR x BP product of more than 3000 mm at the onset of ST depression calls into doubt the validity of the test.

- An HR x BP product of between 2300 and 3000 mm considerably increases the prognostic value of ST depression.

A product of less than 2000 at the onset of ST depression makes it highly probable that two or three major trunks are damaged.

6. Ventricular extrasystoles (figure 27)

The onset of ventricular extrasystoles, or an increase in their frequency during exercise does not definitely establish the presence of stenotic coronary artery lesions. However, in the coronary patient, such signs are an indication of severity, particularly if they are numerous and polymorphic. Notably, they increase the risk of sudden death (7).


FIGURE 27

VA, 51 years, Severe typical angina

## IV - PROGNOSTIC VALUE OF EECG

The validity of EECG has been established by comparison with coronary angiography.

These are two different methods and investigate different phenomena.

The radiological coronary angiographic method is intended to provide information about the anatomical status of the coronary vessels.

The ergometric EECG method is intended to asses the functionalstatus of the coronary circulation. It should not be forgotten that in general ECG reflects only myocardial activity.

The value of the coronary angiograph itself as an indication of anatomical lesions should also be considered.

Some studies (18) have detected the correlation between anatomical stenosis and angiographic signs of stenosis in only 81% of cases. In general, coronary angiography underestimates the presence of stenoses. The method does not explore the fine distal collateral circulation.

The detailed sequence by which coronary artery stenosis may give rise to signs of ischaemia during exercise has not been established.

Coronary angiography (associated with left ventricular angiography) remains the best method of assessing the status of the coronary vessels, but does have its limits and is based on a different principle from that underlying EECG.

All these factors should be borne in mind when assessing an EECG.

False negatives and false positives are merely false with respect to coronary angiography and they may have some significance from other standpoints.

This significance is sought by studies involving longterm follow up of large groups undertaking exercise tests.

Here the question of the PROGNOSTIC VALUE OF EECG is raised.

Figure 28 presents the results of some of these studies.

| | FOLLOW-UP PERIOD | MORTALITY | CORONARY DISEASE | NUMBER OF CASES |
|---|---|---|---|---|
| ROBB, MARKS | 10 years | x 5 | | 2224 |
| DIMOND | 5 years | x 2 | x 3 | 153 railway employees |
| MATTINGLY | 7 years | | x 7 | 836 suspected coronary artery disease cases |
| BRODY | 4 years | | x 16.6 | 756 businessmen |
| RUMBALL, ACHESON | 4 to 7 years | | x 10 | 660 military personnel |
| BELLET, ROMAN | 3 years | | x 9 | 795 healthy male subjects (Bell Tel. Co.) |
| ELLESTAD, WAN | Annual rate | | x 5.6 | 2700 |

FIGURE 28
Multiplying factor (x) of the mortality risk or the risk of coronary artery accident in subjects presenting positive EECG as compared with Normal EECG subjects.

It can be seen that the risk of mortality or of coronary artery accident is significantly higher in positive EECG subjects. The multiplying factor (x) of this risk varies from group to group. This doubtless results from the diversity of the methods, of the criteria for a positive test, of the populations studies, and of the follow up periods.

Other studies provide data of different types.

- DOYLE and KINCH (11) repeated the exercise ECG in a group of 2003 asymptomatic subjects:

  after an initially positive EECG, they detected a 40% risk of coronary accident.

  however if the EECG was initially negative and became positive during a second test, the risk of coronary accident was 85%.

- BLACKBURN (5) found that a negative test did not rule out the possibility of a coronary accident within five years in a population of males aged between 40 and 55 years.

As in FROEHLICHER's study (19) already referred to, this study demonstrated the poor diagnostic value of the EECG in an unselected asymptomatic population.

However it remains true that the coronary risk is statistically lower in negative EECG subjects than in positive EECG subjects.

## V - CONCLUSIONS

The EECG must be interpreted in two manners

1. For a given individual, at a given time, the EECG must be interpreted as follows:

   - taking into account as many criteria as possible which should be systematically analysed: Intensity of exertion, nature of ST shift, HR x BP product etc..

   - taking account of the clinical background and laboratory test findings (age, sex, associated risk factors: high blood cholesterol, smoking, hypertension.....).

2. More generally, the EECG should not be interpreted as a rigid or absolute criterion of the presence or absence of coronary artery disease.

It should be interpreted in terms of the probability of coronary artery disease or of the fairly long term coronary risk.

If viewed from this double point of view, it is the most important risk factor. It is all the more important to take this factor into account because there are other factors of coronary risk.

In an asymptomatic population such as flying personnel and military personnel in general, the EECG cannot reliably be used as a means of mass screening for coronary failure.

This is not simply because of the technical difficulties that this would imply but also because of the lack of specificity of the test in populations of this type.

- However, the author believes that the EECG is of diagnostic value for a sub-group previously selected from within this population on the basis of the extent of the usual factors of coronary risk.

- The EECG may also have prognostic value, which remains to be established, as an indicator of the fairly long term risk of coronary accident.

From this viewpoint the EECG is of increased value for the selection of subjects for high occupational risk posts (astronauts, high performance aircraft pilots etc...) whose future has to be planned for some years in advance.

BIBLIOGRAPHY


1. ASTRAND P.O., RODAHL L.
Text book of work. Physiology, Chap.7, p.214. Mc.Graw Hill book Co ed.New York 1970.

2. ASTRAND P.O., RYHMING J.
A normogram for calculation of aerobic capacity (Physical fitness) from pulse rate during submaximal work. J. Appl. Physiolog. 1954, 7, 218-221.

3. BELLET S., MULLER O.F, LAVAN D., NICHOLS G.J., HERRING A.B.,
Radioelectrocardiography during exercice in patients with anginal syndrome; use of multiple leades. Circulation 1964, 36, 29.

4. BLACKBURN H.,
The exercice electrocardiogram. Technological, procedural, and conceptual developments. In mesurement in exercice electrocardiography. Edited by H.BLACKBURN Spingfield III,1969.

5. BLACKBURN H., TAYLOR H.L., KEYS A.,
The electrocardiogram in prediction of five year coronary heart disease incidence among men aged forty through fifty nine. Circulation 1970, 41-42 (suppl) 1.

6. BLONDEAU M.,
Les critères coronarographiques de l'E.C.G. d'effort. Colloque d'Ambarès 14-15 Octobre 1971.

7. BONORIS P.E., GREENBERG P.S., CHRISTISON G.W., CASTELLANET M.J., ELLESTAD M.H.,
Significance of changes in R. waves amplitude during headmill stress testing = angiographic correlation. American Journal of cardiology : 1878 - 41, 846.

8. BONORIS P.E., GREENBERG P.S., CHRISTISON G.W., CASTELLANET M.J., ELLESTAD M.H.,
Evaluation of R. waves amplitude changes versus ST segment depression in stress testing. Circulation 1978, 57, 904.

9. CHAING B.N.. ALEXANDER E.R., BRUCE R.A., THOMSON D.J., TING N.,
Factors related to ST segment depression after exercice in middle aged chinese men. Circulation 1969, 40, 315.

10. DAVIES C.T.M.,
Limitation to the prediction of maximum oxygen in take, from cardiac frequency measurements. Journ.Appl. Physiol. 1968, 24, 700-706.

11. DOYLE J.I., KINCH S.H.,
The prognosis of an abnormal electrocardiographic stress test. Circulation 1970, 41, 545.

12. ECLACHE J.P., BEAURY J.,
La détermination de l'aptitude physique. Principes méthodologiques et réalisation en pratique militaire. Médecine et Armées 1977, 5, 427-434.

13. ELLESTAD M.H.,
Stress testing : Principle and Pratice. Philadelphia F.A. Davis 1975.

14. EKBLOM B., HERMANSEN L.,
Cardiac output in athletes. J.Appl.Physiol. 1968, 25, 619-625.

15. FARIS J.V., Mc.HENRY P.L., MORRIS S.N.,
Concepts and application of tredmill exercice testing and the exercice electrocardiogram. American Heart Journal. 1978, 95, 102.

16. FENN W.O.,
Acute and sustaned high energy output. In : Symposium on stress 1953, 16-18. Washington D.C. Army Medical Service Graduate School.

17. FLANDROIS R., LACOUR J.R.,
Les adaptations respiratoires et circulatoires de l'exercice musculaire. in HERMANN H., CIER J.F., Précis de Physiologie T.IV, Chap. X, 444-447 - Masson Ed. Paris 1970.

18. FOURNIER C., BARILLON A., PARAISO E., SAUDEMONT J.P., GERBAUX A.,
Comparaison entre les aspects angiographiques et les lésions anatomiques des artères coronaires. Archives des maladies du coeur 1975, 7, 691.

19. FROELICHER V.F., YANOWITZ F., THOMPSON A.J., LANCASTER M.C.,
The correlation of coronary angiography and the abnormal electrocardiographic response to maximal treadmill testing in 76 asymptomatic men. Circulation 1973, 48, 597.

20. GOBEL F.L., NORDSTOM L.A., NELSON A.R., JORGENSEN C.R., WANG Y.,
The rate pressure product as an index of myocardial oxygen consumption during exercice in patients with angina pectoris. Circulation 1977, 57, 549.

21. GUTMAN R.A., ALEXANDER E.R., LI Y.B., CHAING B.N., WATTEN R.H., TING N., BRUCE R.A.,
Delay of ST depression after maximal exercice by walking for 2 minutes. Circulation 1970, 47, 229.

22. HENANE R., ECLACHE J.P., BEAURY J.,
Les facteurs cardio-circulatoires déterminants de l'aptitude physique. Médecine et Armées 1977, 5-3, 217-224.

23. HOLLENBERG M., BUDGE W.R., WISNESKI J.A., GERTZ E.W.,
Treadmill score quantifies electrocardiographic response to exercice and improves test accuracy and reproducibility. Circulation 1980, 61, 2, 276-285.

24. KASSEBAUM
A comparaison of hypoxemia and exercice electrocardiogtaphy in coronary artery disease. American Heart Journal 1968, 75, 6

25. LESBRE J.P., BERNASCONI P., QUIRET J.C., BENS J.L., DUBOISSET M.,
Les epreuves d'effort en cardiologie. Coeur et Medecine Interne 1972, XI, 4, 697-708

26. MASON R.E., LIKAR I., BIERN R.O., ROSS R.S.,
Multiple exercice electrocardiography. Experience in 107 normal subjects and 67 patients with angina pectores, and comparaison with coronary cinearteriography in 84 patients. Circulation 1967, 36, 10, 517-525.

27. MASTER A.M.,
The MASTER two step test. American Heart Journal 1968, 75, 6, 809-837.

28. MITCHELL J.H., SPROULE B.J., CHAMPAN C.B.,
The physiological meaning of the maximal oxygen intake test. J.Clin.Investig. 1958, 37, 538-547.

29. NELSON A.R., GOBEL F.L., JORGENSEN C.R., WANG K, WANG Y., TAYLOR H.L.,
Hemodynamic predictors of myocardial oxygen consumption during static and dynamic exercice. Circulation 1974, 50, 1179.

30. ROQUEBRUNE J.P.,
Efforts et épreuves d'effort en cardiologie. Medicorama 1981, 247.

31. ROWELL L.B., TAYLOR H.L., WANG Y., CARLSON W.,
Saturation of arterial blood with oxygen during maximal exercice. J.Appl.Physiol. 1964, 19, 284-286.

32. SALTIN B., BLOMQUIST C.G., MITCHELL J.H., JOHNSON P.J. (Jr.), WILDENTHAL K., CHAPMAN C.R.,
Reponse to exercice after bed rest and after training. Circulation 1968, 38 supl.7, 1-78.

33. SERRA-DIMIGNI A., BORY M., DJANE P., GAUDY M., BENNE J.G., AUDIER ,
L'électrocardiogramme d'effort dans le diagnostic des coronaropathies. Sa confrontation avec les données de la coronarographie. Colloque d'Ambarès 14-15 Octobre 1971.

34. SHEPHARD R.J., ALLEN C., BENADE A.J.S. et Col.,
Standardisation of submaximal exercice tests. Bulletin O.M.S. 1968, 38, 765-775.

35. THEWS G.,
Gaseous diffusion in the lung and tissues in REEVE and GUYTON. Physicol bases of circulation transport = regulation and exangue - W.B. Saunders Co Ed. Philadelphie 1967.

CHAPTER 4A

# CONTINUOUS ECG MONITORING BY THE HOLTER METHOD

by [illegible] Legaay* and A. Seigneurie*

The development by HOLTER in 1949 of a method making it possible to [illegible] in the active subject, provided not only a picture of the [illegible] of the heart over a period, but also changed some [illegible] particularly [illegible].

The method has undergone continual improvement and is of interest in [illegible]:

- [illegible] and the monitoring of their treatment
- [illegible] disorders

First of all we will consider the technical aspects of the method, and then we [illegible] summary of the main cardiological indications and finally suggest [illegible] Aeronautical Medicine.

## [illegible] ASPECTS OF HOLTER'S METHOD

The various instruments available vary greatly both in design and performance. [illegible] confusion as to the indications, possibilities and limits of the [illegible].

These depend partly on the technical aspects of the various systems which we [illegible].

[illegible] recording assemblies involve three parts:

- [illegible]
- [illegible]
- [illegible]

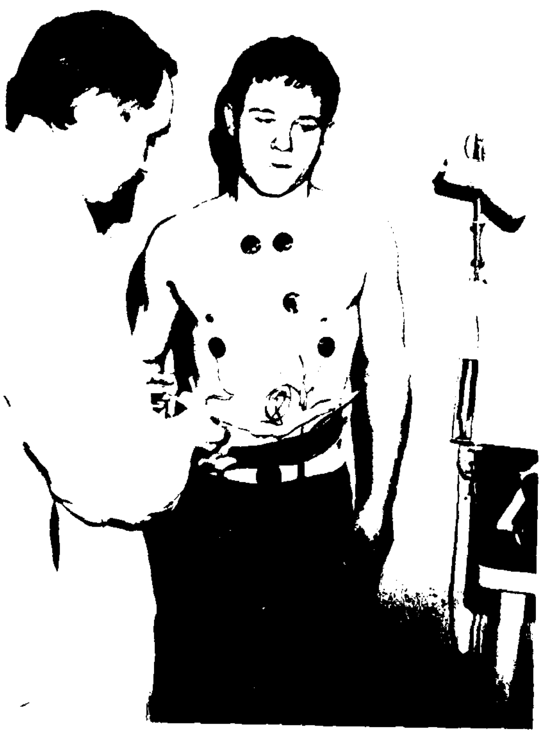


FIGURE 1
24-Hour ECG

Placing the electrodes: Careful preparation of the skin as for an exercise ECG. Self-adhesive electrodes (disposable). Connected to the cable by means of a press stud system

Study by the Service de Médecine Aéronautique et Médecine Interne
Hôpital d'Instruction des Armées Dominique LARREY 78013 -Versailles, FRANCE
* Médecin en Chef : Professeur Agrégé du Service de Santé des Armées.

PRECEDING PAGE BLANK-NOT FILMED

## 1.1 Recorder

The ECG is recorded by means of thoracic electrodes (figure 1)

The recording is made on a magnetic chart which flows at a constant rate and on which it should be possible to mark not only the electrocardiographic signal but also a time base line and an indication of events.

### 1.1.1. Magnetic chart:

At present recording may be made on :
- a magnetic tape
- or on a cassette.

The second method is becoming more and more common. It has the advantage of being easier to handle, but is sometimes said to produce flow problems in recordings lasting for more than 18 hours which may interfere with the reading of the cassette.

One of the drawbacks to the magnetic tape system is wearing of the pinions of the motor. Fortunately it is now possible to replace these. The cassette driving system may also become worn and this should be serviced after six to twelve months of use. The reel is less easy to insert than the cassette and an error may result in a failure to record. This is frequent when one begins to use an apparatus.

If the recordings are to be kept, the cassette system is less expensive.

### 1.1.2. Electricity supply

All instruments are fitted with an independent supply of electricity with a life span of at least 24 hours.
- accumulators which must be recharged after each usage, and this requires the purchase of a charger
- alkaline batteries
- mercury batteries.

Some of these batteries can be recharged.

### 1.1.3. Chart rate and time scale

One of the main contributions of the method is to situate the ECG recording in function of precise moments in the patient's activity. It is therefore important to have a uniform chart rate of the magnetic charge. This is difficult because the speed is very low.

In the most sophisticated instruments there is a quartz clock controlling both the chart rate and the time scale.

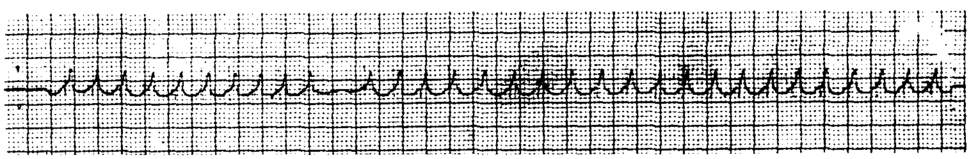


Figure 2 - Contracted recording. Note there is one pause.

### 1.1.4. Event marker

It is also useful if the subject under test can indicate on the recording tape a concise record of events (symptoms, emotions, therapy etc...)

When read, the signal can be compared with the ECG and the time scale.

The event marker is operated by the subject under test and is either incorporated in the control box or else linked to it by a cable which makes it possible for the subject to have it beside his hand.

### 1.1.5. Number of channels

The recording is made from precordial electrodes usually placed on the main axis of the heart so as to pick up maximum signal strength.

Two channel recorders are more reliable. They record from two leads and in this way:
- some parasites can be eliminated
- if an electrode becomes disconnected , which can always happen in a subject asked to continue his normal activity, this is less serious.

1.1.6. Weight

The recorders weigh between 400 and 700 grams, which is generally held to be the maximum acceptable weight. Cassette recorders are generally lighter and can easily be carried on a belt.

1.1.7. Checking the signal

When the recorder is fitted, the signal recorded must be checked against a standard ECG instrument.

By moving the electrodes, it is possible to obtain a signal with a voltage (greater than one minivolt) which the lector can pick up.

This also makes it possible to detect and eliminate some parasites from the outset and to pinpoint changes in the recording in function of the subject's position.

1.2. Lector

The lector is an instrument able to identify normal QRS complexes and to distinguish them from abnormal complexes.

This is done after defining a normal QRS complex.

1.2.1. Definition of the QRS complex and ST segment

The usefulness of a lector depends on the definition of the program (normal QRS). Depending on the type of instrument used, some or all of the following features are taken into account:

- duration of QRS
- amplitude and initial slope of QRS
- several (5) points on QRS
- the area of QRS
- shortening of the interval between QRS and the preceding complex (prematurity)

The performance of the lector and the sophistication of the programme determine the precision of reading.

At best, the lector is able to distinguish the following features:

- normal complexes
- extrasystoles (premature complexes)
- super-ventricular or ventricular nature (narrow or wide complexes)
- wide but not premature complexes (Blocks...)
- salvos of extrasystoles
- R/T phenomena
- pauses.

Depending on the fineness of the tuning of the program, some extrasystoles may pass unrecognized or some parasites may be mistaken for abnormal complexes.

One of the advantages of the lector is flexibility of setting of the parameters used as criteria of abnormal complexes or disturbances of the rhythm .

Definition of the ST segment

Some instruments are able to define the normal ST segments by means, for instance, of an adjustable brightness control.

1.2.2. Lector speed and time scale

Reading speed is 60 to 120 times faster than recording speed. The lector therefore covers a 24-hour tape in 24 to 12 minutes.

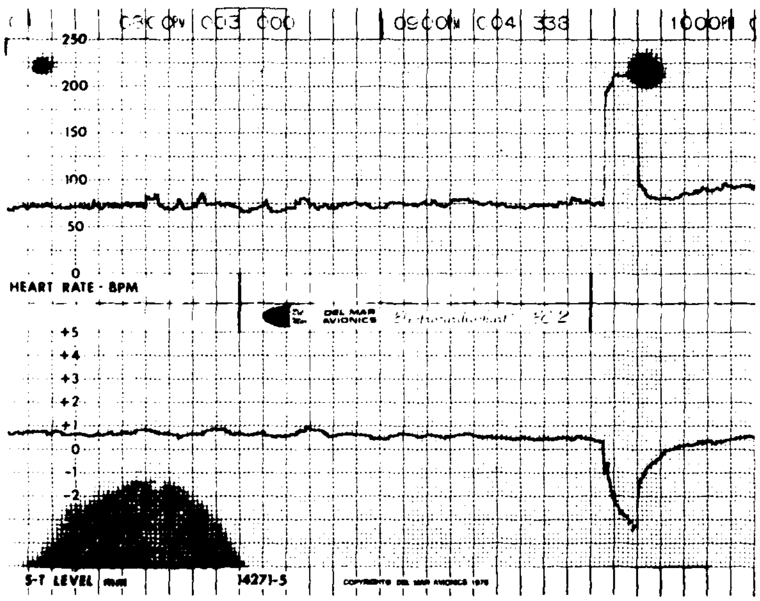



Figure 3 - LEG, 48 years. Sudden chest pains between 10 and 15 minutes.
The "trend" of the heart rate shows an attack of paroxysmal tachycardia.

This does not mean that a tape is always used within the same length of time. *This time varies in function* of the frequency of abnormalities, the requirements of the operator, the technical capacity of the instrument and the quality of the recording.

As for the recorder, some lectors are equipped with a quartz clock to set the chart rate and sometimes to link this to the recorder time scale.

The lector may also display time and some instruments are able to seek and analyze a given section of the recording by replaying a given period.

1.2.3. <u>Screen</u>

All lectors display some or all of the record on a screen in various ways.

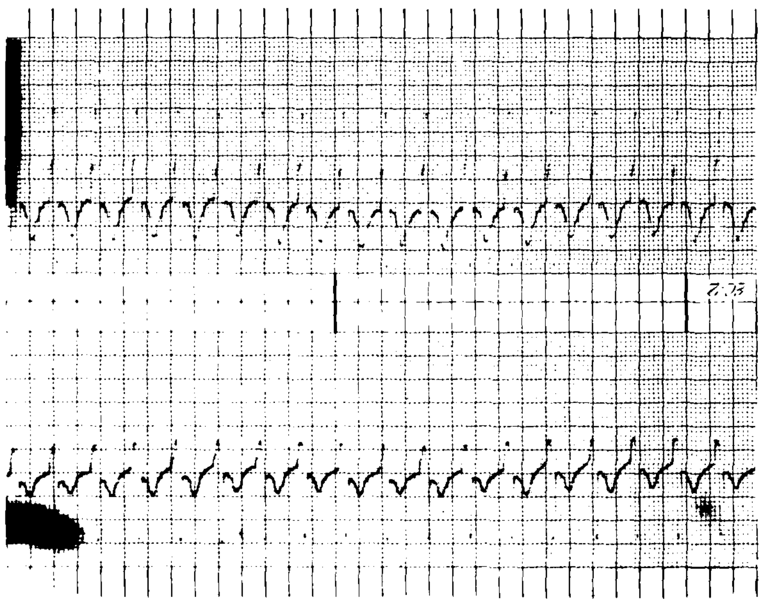
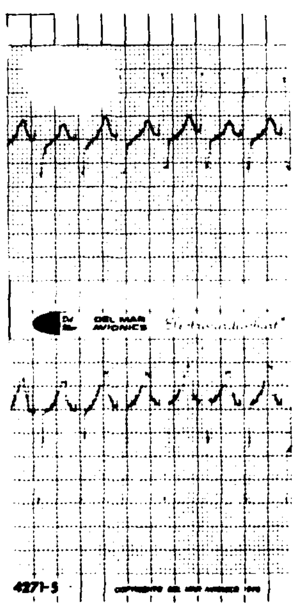


Figure 4




LEG, 48 years. Same patient as figure 2.
Recording of an attack of junctional tachycardia (Bouveret).

Figure 4 B

Continuous display

The ECG is displayed on the screen in the form of one (or two or three) heart cycles by superimposing images, whilst the complexes remain unchanged.

The task of the observer and his skill lies in an ability to spot even fleeting changes of the picture.

Discontinuous display

The screen displays a series of complexes lasting periods of 20 to 40 seconds. The picture remains static whilst the trace is stable. If any change occurs a new series appears. If the lector does not detect any abnormality, the new series remains on the screen.

Some instruments combine both systems. This allows the attentive observer to spot abnormalities on the continuous screen which the lector may have failed to detect.

1.2.4. Sound signal and automatic hold

Some systems can rectify any lack of attentiveness of the observer by:
- either a sound signal
- or the automatic hold of the display for a period which may or may not be extended.

1.2.5. Checking the reading

The lector may take some artefacts for abnormalities and transmit some as such to the automatic analysis system ( see below) (e.g. episodes of parasitic activity mistaken for tachycardia).

To the best of the author's knowledge, there is only one instrument on which it is possible to confirm or efface the passage of a recording classed as abnormal by the lector. Using this system, it is possible to tune the QRS program at the beginning of reading.

1.2.6. The "Jog" Function

When the instrument stops on a change in the record, it may often be useful to examine the moment immediately preceding or following this change. This is made possible by the "Jog" function.

This is usually performed by successive fractions of variable lengths (between 40 seconds and several minutes) . Theoretically, it is possible to check any part of the record but since this is a fairly complex manoeuvre it is a fairly lengthy procedure.

1.2.7. Paper recording

It is necessary to be able to record some abnormalities in the results on paper charts.

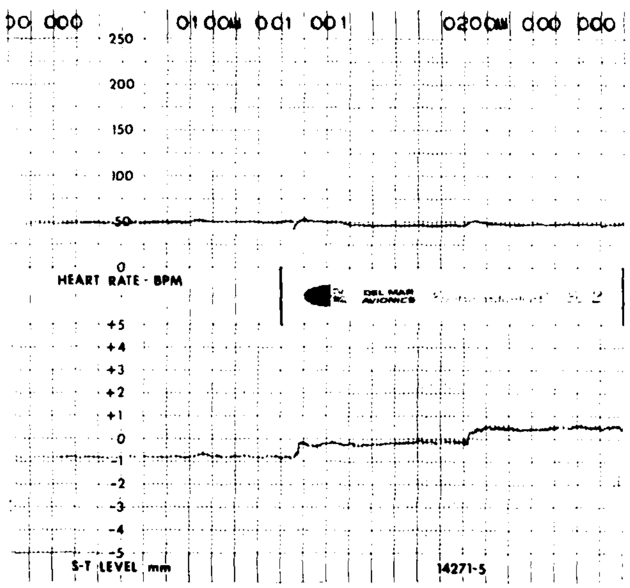



Figure 5 - ESC, 71 years. Chest pain and lipothymia at rest. Moderate ST depression.

Recording possibilities vary from instrument to instrument:

- total and continuous recording
- total but discontinuous recording (of sections lasting a few tenths of a second at intervals of ten minutes or so)
- theoretically it is possible to record on a paper chart but this implies a somewhat lengthy process
- "contracted" recording. It is possible to record at a very low chart rate, with an hour to each page, by means of optic fibres (figure 2)
- the most sophisticated instruments provide automatic recording of pre-selected abnormalities (pause, extrasystoles...) at standard (25 mm/sec) or high speed.

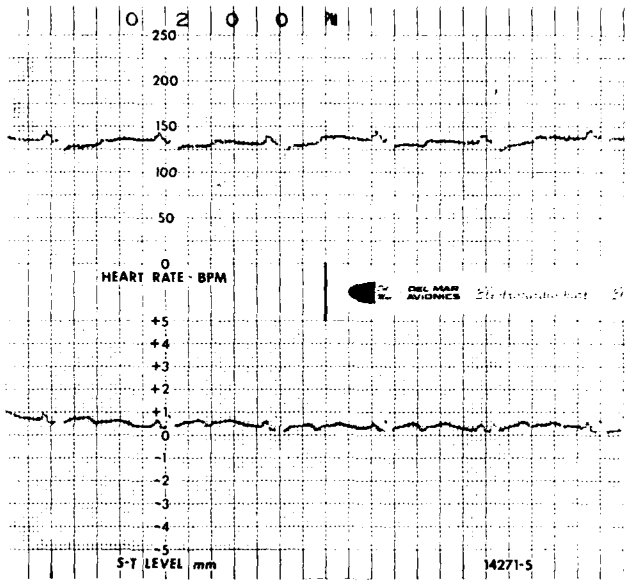



Figure 6 - ESC, 71 years. Same patient as figure 4. Ischaemic ST depression on first channel.

## 1.3. Automatic Analysis (computerised)

Once the lector has recognised the recording, various parameters can be analysed automatically by the computer system and a printout provided :

- either in graph or diagram form
- or as a diagnostic summary

Different instruments offer various possibilities.

### 1.3.1. Numerical data

- heart rate, maximum, minimum, mean
- number of whole complexes
- number of ventricular, supra-ventricular extrasystoles
- number of doublets, triplets
- R/T complexes
- premature
- RR interval above or below a given value
- pauses, bradycardia, tachycardia etc....

1.3.2. <u>Graphs and diagrams</u> (figures 2 to 12)

Many parameters can be represented in graphical or diagrammatic form.

The duration of the RR interval is often presented in the form of a bar histogram. This histograms are made up of bars representing the mean RR during a five or ten minute interval.

Some experience is required to decipher these diagrams, but once mastered they provide rapid detection of disturbances of rhythm.

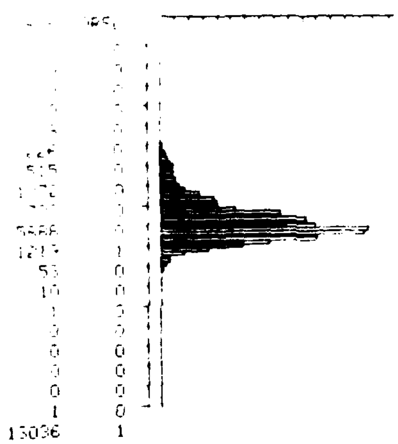
Magnifying effect

It may be useful [illegible] at bars suggesting abnormality and to examine them [illegible] the screen. This is possible by the magnifying effect which is sometimes [illegible] with the "[illegible]" function. It is particularly useful to have a lector able to [illegible] by [illegible] the time of recording (See II-2).

[illegible]

[illegible] may also be represented by a line made up of series [illegible] over a five minute period around a base line.

[illegible] HISTOGRAM : 2200H to 0200H




HISTOGRAM OF DEVIATIONS : 2200H to 0200H

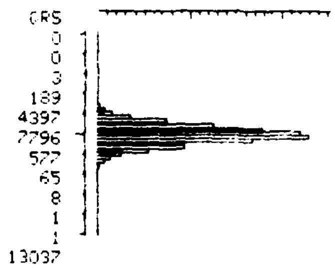



Figure 7 - Athlete aged 30 years, referred because of intermitter PR prolongation.
RR histogram shows spreading at the base ( occasional lc RR).

1.3.3. Diagnostic aid

The most sophisticated systems even provide a synthetic summary and diagnostic pointers.

The program has to be sufficiently specific to avoid errors in reading and sufficiently complex to detect all abnormalities. This system requires a totally reliable instrument and this may not yet be available.

IN SUMMARY

Specific criteria can be required of the various instruments provided by the manufacturers. But it is difficult if not impossible to draw up an absolute "league table" of instruments.

Their selection is based on the use which one intends to make of them; research, or clinical (particularly rhythm disturbances, coronary failure). The decision is also influenced by the availability of the physicians who are to use it and of their experience.

The authors are worried by the danger of widespread use of fully automated systems where the physician is not involved.

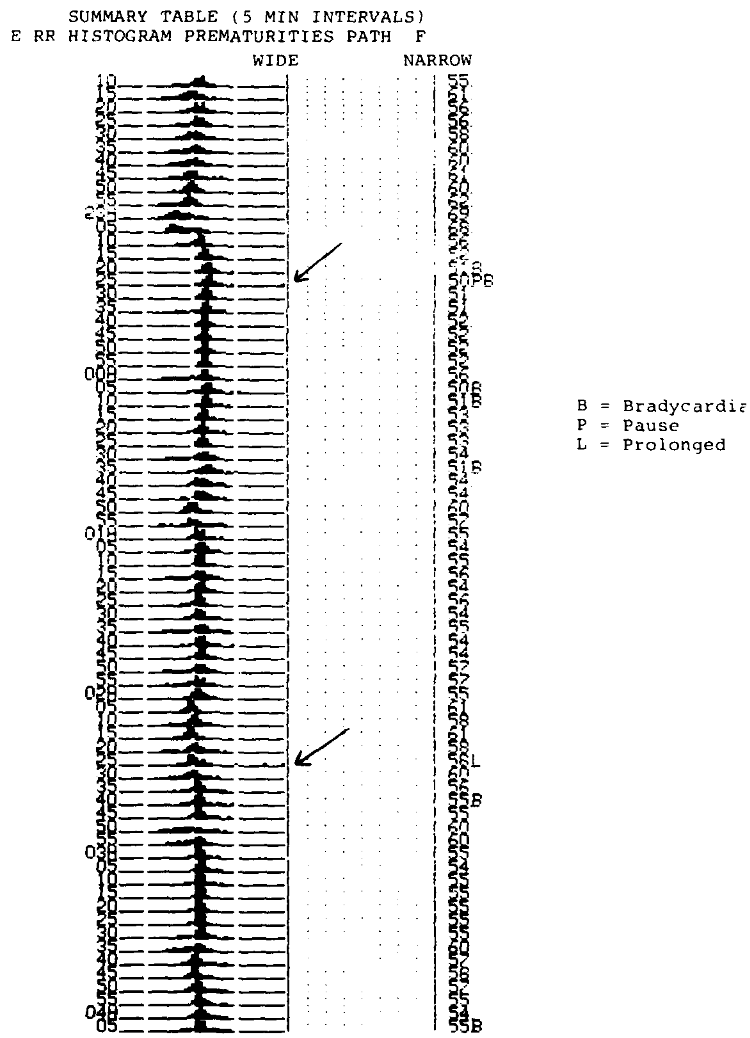



Figure 8 - The same patient as in figure 1. The histogram shows very long RR at about 2325 hours and 0225 hours.

II - VALUE AND EXPERIENCE ACQUIRED IN CARDIOLOGY

The Holter method of continuous ECG monitoring of the active subject made it possible, as clinicians had long hoped, to correlate paroxysmal functional disorders (loss of consciousness, pain etc...) with ECG modifications.

The method is now very widely used and has proved very valuable. Many studies have been and continue to be performed to investigate this method which continues to be highly relevant.

We cannot hope to list all such studies. We will present the main indications for the method as we listed them in a previous article (29).

In asymptomatic subjects

The method is useful particularly in order to establish the limits of the normal range. Extensive studies of all age groups have been carried out (2-6).

These studies have established the high frequency of sinus function disorders in young subjects during sleep and the high percentage of ventricular arrhythmias in the elderly. Some of the abnormalities detected have established the importance of rhythm disturbances in the etiology of sudden deaths.

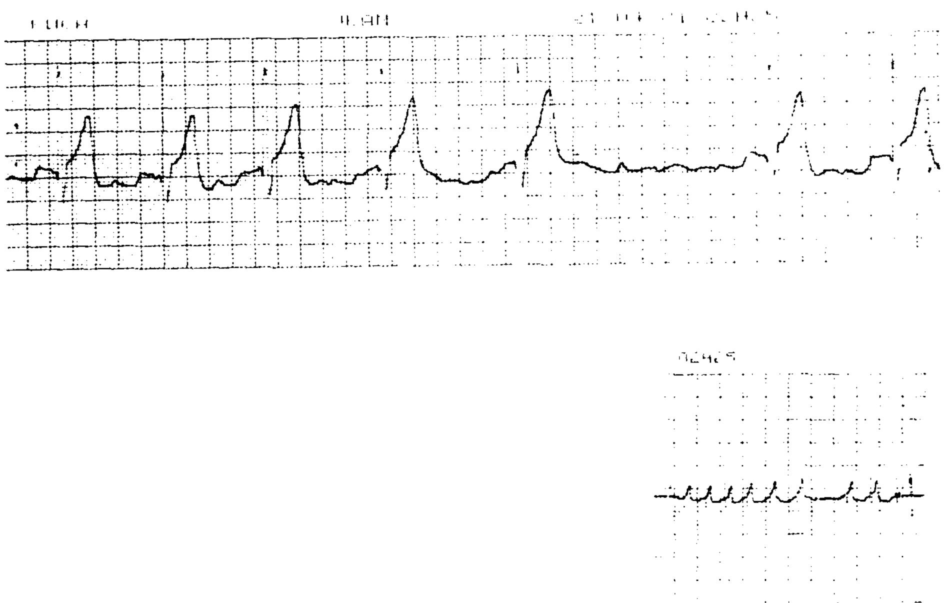


Figure 9 - Same patient as in figures 6 and 7
Actual size recording of the pause detected in the RR histogram, figure 7.

Bottom right, contracted *recording over 40 sec.*

Symptoms suggesting paroxysmal arrhythmias

The symptomatology may be *predominantly cardiac* (palpitations), irregularities of rhythm or neurological ; lipothymia, vertigo, syncopy, or actual loss of consciousness)

This method of recording over a 24-hour period is of greater diagnostic value than a standard ECG even if fairly prolonged (15).

The method may seem disappointing both because many malaises are devoid of any accompanying disturbance of cardiac rhythm and also because in order to be of value, it would be necessary to record during the symptoms (3-7).

However, some authors report 25% of *cases* in which symptoms did occur during continuous recording (18).

Other statistical data show that up to 34% of arrhythmias were detected which were classed as severe and required the fitting of a pacemaker. (14-25).

SERVICE MED AERO
NAME
FORENAME JEAN CLAUDE
AGE 30 YEARS
DATE 21-04-81
TIME BEGINNING 10H/10Mn

HOUR BY HOUR RECORD

| | | | | | |
|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | |
| | [illegible] | [illegible] | [illegible] | 0 | |
| [illegible] | 4[illegible] | 0 | [illegible] | [illegible] | |
| | [illegible] | [illegible] | 0 | 0 | |
| [illegible] | [illegible] | [illegible] | 0 | 0 | |
| | [illegible] | 0 | 0 | 0 | |
| [illegible] | 4[illegible] | [illegible] | 0 | 0 | |
| | [illegible] | 0 | 0 | 0 | |
| [illegible] | 4[illegible]55 | 0 | 0 | 0 | |
| | 0 | 0 | [illegible] | 0 | |
| [illegible] | 4[illegible]05 | 0 | 0 | 0 | |
| | 0 | 0 | 0 | 0 | |
| 16H | 4[illegible]65 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 17H | 47[illegible] | 0 | 0 | [illegible] | |
| L | 0 | 0 | 0 | 0 | |
| 18H | 4229 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 19H | 4[illegible]34 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 20H | 3922 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 21H | 3526 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 22H | 339[illegible] | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 23H | 3225 | 0 | 0 | 0 | Pause: 1 |
| L | 0 | 0 | 0 | 0 | |
| 0H | 3162 | 0 | 0 | 0 | |
| L | [illegible] | 0 | 0 | 0 | |
| 1H | 3266 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 2H | 3[illegible] | 0 | 0 | 0 | Long period: 3 |
| L | 0 | 0 | 0 | 0 | |
| 3H | 3319 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 4H | 3239 | 1 | 0 | 0 | LP: 1 |
| L | 0 | 0 | 0 | 0 | |
| 5H | 3405 | 0 | 0 | 0 | LP: 2 |
| L | 0 | 0 | 0 | 0 | |
| 6H | 3285 | 0 | 0 | 0 | LP: 2 |
| L | 0 | 0 | 0 | 0 | |
| 7H | 4704 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 8H | 4683 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |
| 9H | 289 | 0 | 0 | 0 | |
| L | 0 | 0 | 0 | 0 | |

69515 QRS
QRS WIDE
NARROW PREMATURITIES
NARROW DOUBLETS
SALVOS OF NARROW WAVES
WIDE PREMATURITIES
WIDE DOUBLETS
WIDE SALVOS
R/T
PAUSES
PROLONGED
INTERPOLATED

Figure 10

Overall 24-hour results showing pauses and prolonged periods (LP )
Same patient as figures 6, 7 and 8.

SUMMARY TABLE
(5 MIN INTERVALS)
E RR HISTOGRAM PREMATURITIES PATH F

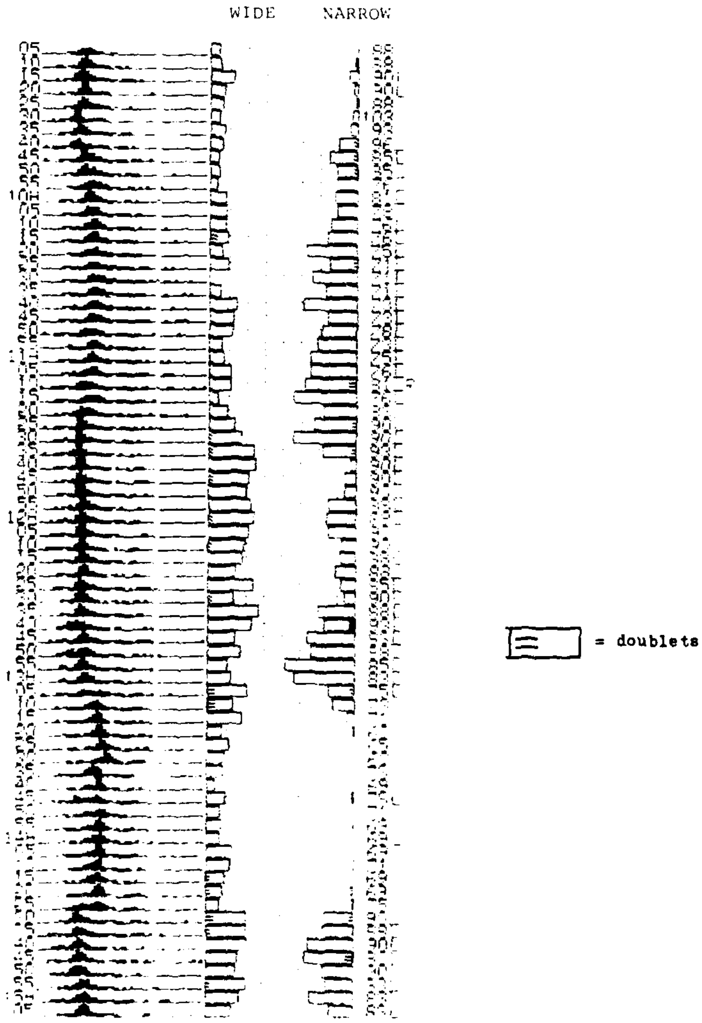



Figure 11 - MAI, 48 years. Ischaemic heart.
History of infarctus.
Recording from 0905 hours to 1505 hours
Very frequent extrasystoles.

SUMMARY TABLE
(5 MIN INTERVALS)
F RR HISTOGRAM PREMATURITIES PATH F

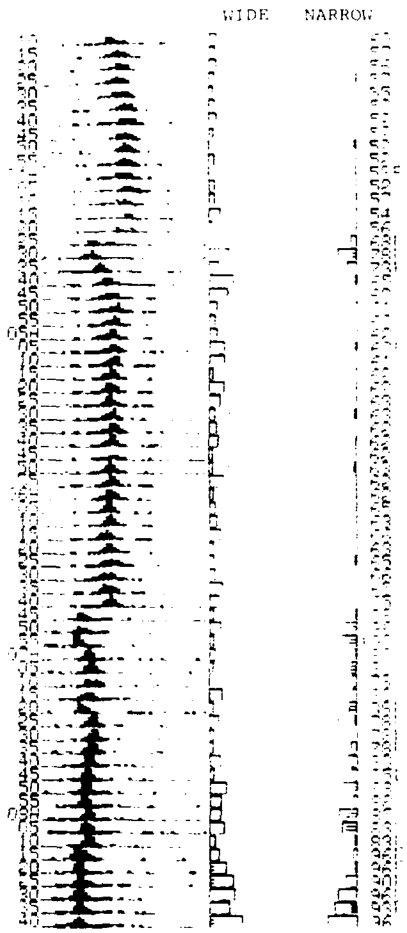



Figure 12 - Same patient as figure 10. Night-time recording: 0310 h to 0840 h.

Comparison of the two recordings reveals that the ventricular extrasystoles were related to tachycardia and to activity in general. When resting during the night, cardiac function decreased and the ventricular extrasystoles became less frequent. When activity was resumed, cardiac function increased and ES reappeared.

Symptoms suggesting transitory coronary failure

This method is obviously of value in some specific conditions: Prinzmetal angina, crisis triggered by particular stress situations, elderly or hypertensive patients.

This method is not an alternative to ECG but provides useful additional information.

The Hôpital BROUSSAIS team (24) have reported their findings of correlation between a positive HOLTER test and coronary lesions and between a negative HOLTER and the absence of coronary lesions.

Studies comparing rhythm disturbances recorded during an exercise test and during a 24-hour continuous ECG, show little contradiction with respect to the comparative reliability of the two methods (22,11).

However it would seem that different types of abnormality are revealed by the two methods. The HOLTER method would seem to be very useful in specific psychological stress situations (for instance driving a motor car...).

Patients presenting ventricular extrasystoles

This is particularly useful in the investigation of the risk of sudden death in patients with ventricular excitability disturbances.

This has made it possible to detect totally asymptomatic ventricular tachycardia (1-27).

Correlations have been established between the onset of such episodes and the frequency of extrasystoles, their coupling, their uni- or multi-focal character and the presence of R or T phenomena.

The influence of these ventricular arrhythmias on the risk of sudden death varies greatly depending whether the heart is apparently healthy or if there is a history of myocardial infarction

Patients with a history of infarction

Many studies have investigated the frequency of disturbances of rhythm, the most likely time of onset and the prognostic significance.

All these studies confirm the frequency of such disturbances of rhythm both during the intial phase and that of the first month following necrosis. It has been shown that marked abnormalities of ventricular excitability affect the vital prognosis of the patients in which they occur.

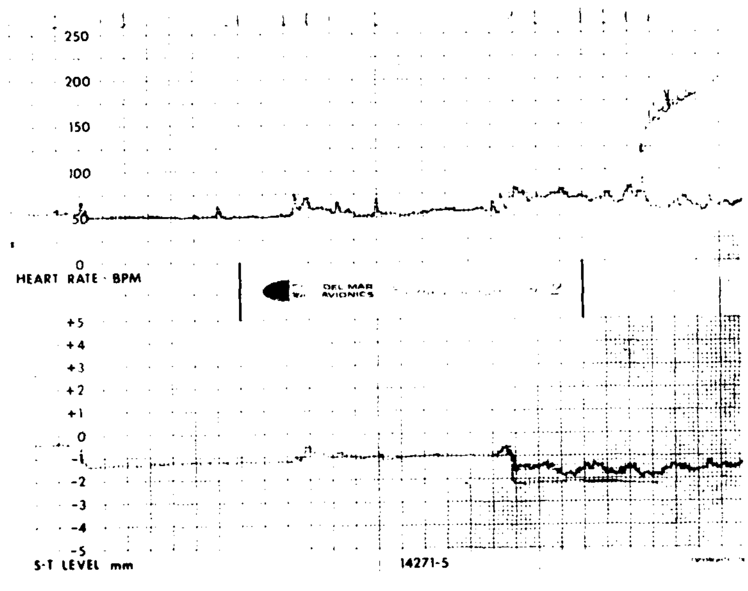



Figure A OBR, 39 years
Precordial pain in a motor car. No ST depression.

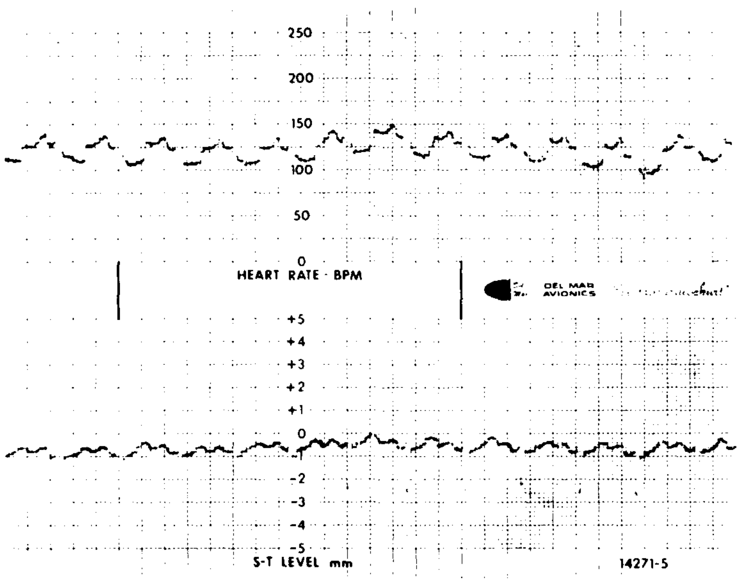



Figure B - OBR. Same patient as figure A
No ST depression on first channel

The ambulatory ECG is also a useful method of monitoring the coronary patient during the rehabilitation period and provides a fairly reliable assessment of the adaptation of the cardiovascular system to the exertion required (8).

Various cardiac disorders

Attempts have been made to evaluate the risk of sudden death in both obstructive and non-obstructive myocardiopathy (23).

These have demonstrated the frequency of rhythm disturbances in the obstructive form and the influence of episodes of ventricular tachycardia on the risk of sudden death.

A detailed study of rhythm in mitral prolapse (26) has been carried out. This has shown the high frequency of such disturbances in some patients and the correlation of this feature with the repolarisation abnormalities long detected in BARLOW's syndrome. Routine 24-hour ECG monitoring is suggested by several authors for this condition.

Evaluation of therapy

This is the major indication for this method which provides four types of information:

- concerning the efficacy of antiarrhythmics, which can no longer be considered without fairly prolonged ECG. Statistical methods have established certain criteria which demonstrate antiarrhythmic activity (20-21-28).

If the time of medication is accurately recorded, this method can also be used to determine the speed and duration of action of the drug, factors which influence the nature of prescription (12-13).

- monitoring of heart pacemakers.
Intermittent malfunction is often difficult to demonstrate and requires prolonged investigation paying particular attention to changes of position of the patient. A continuous ECG, especially if it covers the period of any malaise which may occur, may provide new information very helpful in detecting the fault. The method may also reveal some arrhythmias produced by the pacemaker and not detected by the patient (1).

The treatment of coronary artery disease patients should also be monitored both with respect to efficacy on any repolarisation disorders and on rhythm. Such monitoring should be performed under more physiological conditions than those of the exercise ECG.

- the cardiotoxicity of drugs can to some extent be assessed by their effect on heart rhythm and repolarisation.

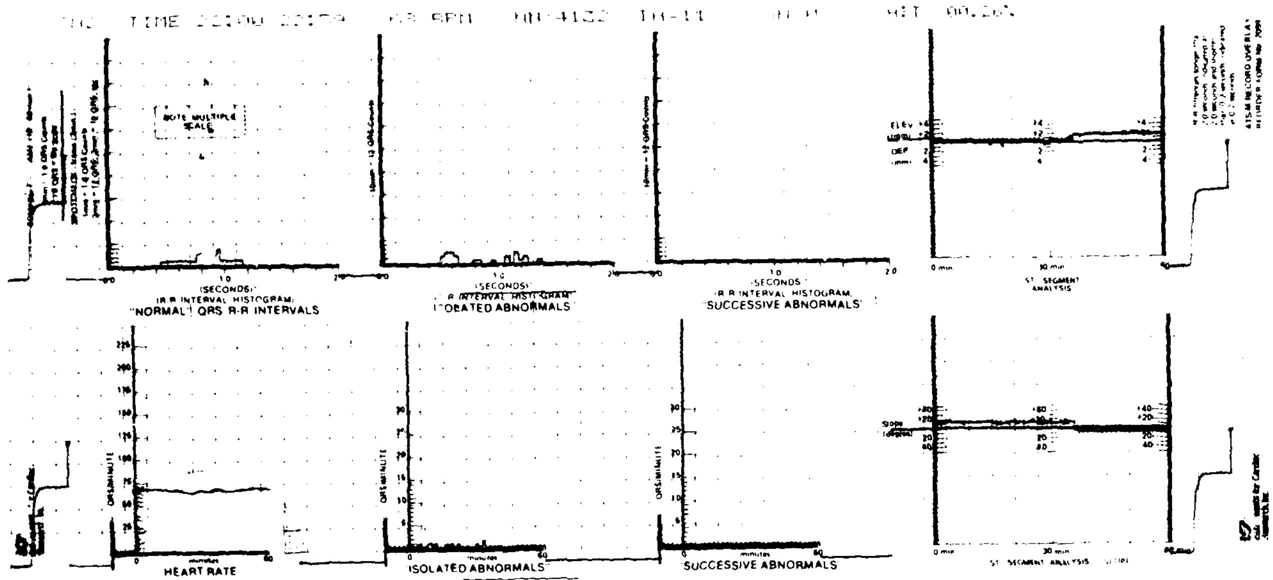



Figure N° Upper histograms, showing RR, isolated extrasystoles, salvos. "Trends" below showing heart rate, extrasystoles, and salvos. The two diagrams on the right are tends showing the shift of ST (above) or the slope of ST (below). Recorded over 1 hour.

BIBLIOGRAPHY


1 - BLEIFER S.V., BLEIFER D.J., HANSMANN D.R.
Diagnosis of occult arrhytmias by Holter electrocardiography.
Progr. Card. Dis. , 1974, 16, 569.

2 - BRODSKY M.
Arrhytmias documented by hours continous electrocardiographic monitoring in 50 male medical students without apparent heart disease.
Amer. J. Cardiol. 1977, 39, 390.

3 - COUMEL Ph., ATTUEL P., MUGICA J.
Enregistrement électrocardiographique continu. Intérêt clinique, diagnostique, et thérapeutique.
Archives des maladies du coeur, 1975, 68, 941.

4 - COUMEL Ph., ATTUEL P., LECLERCQ J.F.
Enregistrement ECG au long cours. In : les troubles du rythme cardiaque.
Groupe de rythmologie de la Société Française de Cardiologie.
Paris, Corbière, ed. 1978, 59.

5 - DJIANE P., EGRE A., BORY M., SERRADIMIGNI A.
Enregistrement continu de l'ECG ( procédé Holter) à la phase hospitalière de l'infarctus du myocarde.
Archives des maladies du coeur. 1978, 71, 1191.

6 - DJIANE P., EGRE A., BORY M., SAVIN B., SERRADIMIGNI A.
L'enregistrement électrocardiographique continu ( procédé de Holter) chez les sujets normaux.
Communication. Société Française de Cardiologie. Séance du 17.12.1978.
Archives des Maladies du Coeur : 1979, 72, 655.

7 - FILLETTE F., FRANK R., GROGOGEAT Y.
Les enregistrements de longue durée de l'électrocardiogramme.
Concours médical, 1978, 100, 4663.

8 - FLETCHER G.F., JOHNSTON B.L.
Dynamic electrocardiographic monitoring during early coitus in patients post myocardial infarction and revascularization .
Abstracts Circulation, 1978, 58, 182.

9 - HOLTER N.J.
New method for heart studies : continuous electrocardiography of active subject over long periods is now practical.

10 - KOPPER G.M., BECKMANN C.H., HALL W.
Ventricular arrhytmia detection after acute myocardial infarction.
Abstracts Circulation, 1978, 57, 177.

11 - KOSOWSKY B.D., LOWN B., WHITING R., GUINEY T.
Occurence of vent-ricular arrhytmias exercise as compared to monitoring.
Circulation, 1971, 44, 862.

12 - LECLERCQ J.F., ATTUEL P., COUMEL Ph.
Evaluation quantitative de l'efficacité des antiarythmiques dans les troubles du rythme ventriculaire chroniques par la méthode de Holter.
Archives des maladies du coeur, 1978, 71, 1192.

13 - LECLERCQ J.F., ATTUEL P., COUMEL Ph.
Intérêt de la surveillance ECG continue pour le diagnostic et le traitement des troubles du rythme.
Cah. Med., 1979, 4, 16, 1075.

14 - LICHT J., PRATT C.M., VERA Z., FASHINELL T.R., AMSTERDAM E.A., MASON D.T., DEMARIA A.N.
High prevalence of cardiac dysryhtmias in the etiology of syncope and dizziness.
Value of assess-ment and documentation by ambulatory monitoring.
Abstracts Circulation, 1978, 58, 92.

15 - LIPSKI J., COHEN L., ESPINOZA J., MOTRO M., DACK S., DONOSO E.
Value of Holter monitoring in assessing cardiac arrhytmias in symptomatic patients.
The Amer. J. Cardiol., 1976, 37, 102

16 - MARCO J., BARADAT G., CHAPELET A., ALIBELLI M.J., CONSTANS R., DARDENNE P.
L'électrocardiographie dynamique par système de Holter en phase tardive d'hospitalisation pour infarctus du myocarde récent. Incidence thérapeutique et valeur pronostique dans une série de 100 patients.
Communication. Société Française de Cardiologie. Séance du 17. 12. 1978.
Archives des Maladies du Coeur : 1979 . 72 . 376.

17 - MEILHAC B., FLEURY G., HEULIN A., LEPAILLEUR C., VACHERON A., DIMATTEO J.
Confrontation de l'enregistrement continu ambulatoire de l'ECG de 24 heures et des explorations endocavitaires dans le diagnostic des troubles du rythme cardiaque.
Archives des maladies du coeur, 1978, 71, 1341.

18 - MEILHAC B., FLEURY G.
Intérêt de l'enregistrement continu ambulatoire de l'électrocardiogramme dans le dépistage des troubles du rythme.
Concours Médical, 1978, 100, 233.

19 - MEILHAC B.
Intérêt de l'enregistrement continu de l'électrocardiogramme dans les 24 premières heures de l'infarctus du myocarde.
Concours Médical, 1978, 100, 6164.

20 - MORGANROTH J., HOROWITZ L.N., JOSEPHSON M.E., MICHELSON E.L.
Marked variations i nthe frequency of ventricular ectopy detected by serial Holter monitoring.
Abstracts Circulation, 1977, 56 supp. III 178

21 - MORGANROTH J., MICHELSON E.L., HOROWITZ L.N., JOSEPHSON M.E., PEARLMAN A.S., DUNKMAN W.B.
Limitations of routine long term ambulatory electrocardiographic monitoring to assess ventricular ectopic frequency.
Circulation, 1978, 58, 408.

22 - RYAN M., LOWN B., HORN H.
Comparison of ventricular ectopic activity during 24 hours monitoring and exercise testing in patients with coronary heart disease.
The New England J. of Med., 1975, 30, 224.

23 - SAVAGE D.D., SEIDER S.F.
24 hours ambulatory electrocardiographic monitoring of patients with obstructive hypertrophic cardiomyopathy.
Abstracts Circulation, 1977, 56, 216.

24 - SELLIER Ph., PROUST F., DELEBARRE Ph., GUERMONPREZ J.L., CURBAK P., MAURICE P.
L'enregistrement électrocardiographique continu dans l'insuffisance coronaire. Intérêt diagnostique.
Archives des maladies du coeur, 1978, 71, 638 .

25 - SWENSON R.D., PRICE J.E., FASHINELL T.R., PRATT C.M. AMSTERDAM E.A. , MASON D.T. DEMARIA A.N.
High prevalence of cardiac dysrhytmias in the etiology of syncope and dizziness: documentation by ambulatory monitoring.
Abstracts Circulation. 1977, 56, 24.

26 - WINKLE R.A. , LOPES J., GOODMAN C.H.
Detailed analysis of ambulatory arrhytmias in patients with mitral valve prolapse.
Amer. J. Card., 1975, 35, 178.

27 - WINKLE R.A., DERRINGTON D.C., SCHROEDER J.S.
Characteristics of ventricular tachycardia in ambulatory patients.
The Amer. J. Cardiol., 1977, 39, 487.

28 - WINKLE R.A.
Spontaneous variation in ventricular ectopy mimics antiarryhtmic drug response.
Abstracts Circulation, 1977, 55 supp. II 179

29 - SEIGNEURIC A., LEGUAY G.
Electrocardiogramme continu ambulatoire. Méthodes. Indications.
A paraître in Médecine et Armées, 1979 - N° 8
7, 9, P. 841 - 845.

CHAPTER 4B

# THE HOLTER METHOD IN AERONAUTICAL MEDICINE

by G. Leguay* and A. Seigneuric*

The small number of publications dealing with continuous ECG recordings in aeronautical medicine is in marked cont ast to the wealth of literature concerning the use of the method in cardiology.

Most of the publications wh ch have appeared deal with pilots of transport aircraft only.

Sometimes only the heart rate was determined. Such studies are essentially ergometric and assess the work load from the heart rate (3).

Other studies involved only very small numbers of subjects (1-4 cases) or relatively short periods (1-8 hours).

Others again are purely technical research into instrumentation (5,6,8)

The large number of criteria of normality defined for flying personnel is recognised as one of the problems posed by the immediate use of the method (1).

The method is of use in various fields of aeronautical medicine.

## 1. Study of cardiac performance of pilots during flight

This type of study may concern:

- the fighter pilot subjected to *extreme accelerations*
- the pilot of transport aircraft subjected to disturbances of the circadian rhythm.

The authors believe that the question of tolerance of acceleration is of great importance. Many studies are currently devoted to tolerance of the high accelerations tc which the pilots of new generations of fighter aircraft will be subjected (9,10,11).

The HOLTER method makes it possible to record the electrical activity of the pilot's heart during all the operations of the different types of mission (taking off, landing, aeronautical display, acceleration, low or high altitudes etc...)

## 2. Defining criteria of normality

It is possible to define criteria of normality from data gathered from a sufficiently large population.

The appearance and frequency of ventricular extrasystoles at certain levels of acceleration for instance.

Tachycardia during landing, taking off etc...

## 3. Pilot adaptation

Just as for instance the degree of training of an athlete can be monitored from the ECG, so too some ECG features will reflect the adaptation of flying personnel to f.ying.

Vagal tone, for instance, is known to be modified by aeronautical experience (12) and can be used to estimate the degree of adaptation. ECG provides a good indication of vagal tone.

The three points of interest considered above are also amply documented by continuous ECG monitoring during space flights (13-14).

The following have been defined:
- Specific ECG changes in space
- The frequency and usually good tolerance of some disorders (ventricular extrasystoles).

Analysis of the ECG and of the changes it undergoes has led to alterations of the schedule of work and rest periods .

Somewhat paradoxically, the research concerning cosmonauts has yet to be done in aircraft pilots.

## 4. Diagnostic tool and certification of fitness. Air safety

Three fields of cardiology pose special problems of flying fitness:
- extrasystoles
- minor conduction disorders
- primary repolarisation disorders

In general, these problems are mild. However they must be distinguished from the occasional severe case. In flight ECG may be useful.

* Médecin en Chef; Professeur Agrégé du Service de Santé des Armées.

Such a method would not be to the detriment of the pilot tested. The inflight pattern of the disorders listed is still unknown and so the examining expert tends to be severe, rightly stressing AIR SAFETY.

Confirmation of good cardiac tolerance of flight is a feature which contributes to AIR SAFETY and is useful in fitness assessment.

The inflight use of the HOLTER method could also be exploited to assess currently used expert report tests such as the human centrifuge.

The method would also provide information concerning the wide field of INFLIGHT MALAISES. Here too, it would contribute to AIR SAFETY.

## BIBLIOGRAPHY


1 - DIETZ A., WALTER J.
The signifiance of rythm disturbances in asymptomatic persons.
A.G.A.R.D. Conference Proceedings ( G.B.)
Vol. C.P. 231 - n° 6 - 10/1977.

2 - RAMACCI C.A. ; ROTA P.
Comportemento psicofisiolosico di alliovi piloti durante le prime missione di volo ed idoneita al pilotassio.
Rivista di Medicina Aeronautica et Spaziale ( IT)
1975 - 38, 1, p. 3-20.

2 bis- RAMACCI C.A. ; ROTA P.
Flight fitness and psycho-physiological behavior of applicant pilots in the first flight missions.
A.G.A.R.D. Conférence Proceedings ( G.B.)
Vol. C.P. 153 - n° 8 - 3/1975

3 - SCHANE W.P.
Continuous E.C.G. recording of helicopter instructor pilots.
Aerospace Medicine (U.S.)
1972 - 43 - 5 - p. 560-563

4 - SEKIGUCHI C. ; YAMAGUCHI O. ; KITAJIMA T. ; UETIA Y.
Continuous E.C.G. monitoring on civil air crews during flight operations.
Aviation space and Environmental Medicine ( U.S.)
1977, 48, 9, p. 872-876.

5 - SEM JACOBSEN C.W.
E.C.G. monitoring of heart failure and pilot load by the Vesla seat pad.
Aviation Space and Environmental Medicine ( U.S.)
1976, 47, 4, p. 441-444.

6 - SIROT J.
Un dispositif de sécurité à bord des avions de ligne : captation de l'électrocardiogramme par l'intermédiaire d'un siège pourvu d'électrodes.
La nouvelle presse médicale ( F.)
1974, 36, 3, p. 2350-2351.

7 - WALTER W.H. ; GRASSMAN E.D. ; ENGELKEN E.S. ; LANCASTER M.C.
Extended electrocardiographic monitoring with emphasis on computer analysis of records.
A.G.A.R.D. Conference Proceedings ( G.B.) 1972-7.

8 - WOERLEE R.L.
The P.O.P. 15 electrocardiographic monitoring with emphasis on computer analysis of records.
A.G.A.R.D. Conference Proceedings ( G.B.) 1972-7.

8 bis- WOERLEE R.L.
The P.O.P. 15 electrocardiogram analysis system : a further attempt at continuous real time operations Master Thesis.
Air Force Inst. of Technology - Wright Patterson A.F.B.
Ohio School of Enginering.
Dec. 1975 - 129 p. rept. n° GE/BE/75-44

9 - LEGUAY G ; AUFFRET R.
Apport de la Médecine Aéronautique à la Cardiologie.
Annales de la Cardiologie et Angéiologie.
1978 - 27 - 563-569.

10 - LEGUAY G. ; SEIGNEURIC A. ; JACOB G.
Cardiomyopathie des accélérations.
Médecine et Armées - 1979 , 4 , p. 327-331

11 - LEGUAY G. ; SEIGNEURIC A. ; DRONIOU J. ; PERNOD J.
Prolapsus mitral et accélérations.
Revue de Médecine Aéronautique et Spatiale.
1978, 67, 229-235.

12 - GRANDPIERRE R. ; GROGNOT P.
Etude de l'état neuro-végétatif du Personnel Navigant en période de repos.
Rapports 1 et 2 à l'Inspection Médico-Physiologique de l'Armée de l'Air.
1937.

13 - BIOMEDICAL RESULTS OF APOLLO.
1975 - Scientific and technical information office national aeronautics and space administration.
WASHINGTON D.C. - U.S.A.

# CHAPTER 5

## CONTRIBUTION OF STANDARD X-RAY TO CARDIOVASCULAR EXPLORATION DURING THE CLINICAL EXAMINATION OF FLYING PERSONNEL

by M. Puech* and P.J. Metges **

I Teleradiography and televised fluoroscopy of the heart are combined within a battery of complementary cardiological examinations .
We will present the non-invasive radiological methods used in the expert examination of FP and discuss normal results and the contribution of these methods in some abnormalities which are usually slight but which may pose problems concerning fitness.

## II RADIOLOGICAL METHODS

### A) Cardiac Roentgenography

This method provides objective and reproducible information concerning the shape of the heart. The method is accurate and completely reproducible but accurate and completely reproducible technical conditions are required:

(1) Four positions are used:
- *frontal*
- left lateral
- left anterior 60° oblique
- right anterior 50° oblique

These determinations are carried out with the apparatus set at a given angle.
(2) The X-rays are taken following deep inspiration with the subject upright.
(3) In order to offset photographic *enlargement*, the distance between the focus and the film should be at least two metres. In conventional chest X-ray the distance is less than 1 metre and this explains the usual distortion of the heart outline. Under such conditions, cardiomegaly is frequently falsely concluded and any localised abnormality detected must be confirmed by *tele roentgenography.*
(4) Barium sulphate opacification of the oesophagus is routine because of the close contact between the posterior border of the left atrium and of the aortic nob with the oesophagus.
(5) High voltage (120 Kv) is always used, this provides:
- minimal exposure time
- visualisation of the heart and mediastinal lines.

IN CONCLUSION basic X-ray examination involves four X-rays taken under high voltage after barium opacification of the oesophagus. This series of four roentgenographic positions is easy to carry out and reproducible.

### B) Heart Fluoroscopy

is always carried out with brightness amplification.
The display period is short so that the patient is exposed to minimal irradiation.
It is useful to record the findings on a videotape since this provides a document which can be studied at leisure and allows for holding of a particular image or replay of some sections.
The performance of the examination is provided by the information provided by the expert physician and by the findings of standard X-rays. The following procedures should be carried out:
(1) Analysis of the contraction of the left ventricle shown from the frontal and two oblique angles: the kinetics of the antero-lateral walls and the tip of the heart is analysed from frontal and right anterior oblique angles, that of the lateral wall and posterior wall from the left anterior oblique .
(2) Study of the kinetics of the trunk of the pulmonary artery from the frontal and slight (30°) oblique right anterior. The systolic expansion of this segment should routinely be investigated and, can confirm a diagnosis of interatrial communication.
(3) Study of the expansion of the ascending aorta in a left oblique position.
(4) *Assessment of an abnormal* and paradoxical expansion of the left atrium in a left anterior oblique position signifying mitral failure.
(5) Routine screening for cardiac calcification. Investigation of their form, appearance and mobility. The etiology, coronary, mitral or aortic valvular, endocardial, myocardial or pericardial origin, is also dicussed.

IN CONCLUSION Televised fluoroscopy with video recording provides much information but must be used methodically and carefully in order to analyse the shape and dynamic features of the heart cavities, the aorta, of the pulmonary arteries and to obtain information useful to the examining physician.

* Médecin Principal, head of the Radiology Unit of CPEMPN
** Médecin en Chef, head of the Radiology Unit of H.I.A. BEGIN
Professeur agrégé at E.S.S.A.A. - CERMA (chair of Electroradiology)

## I.1 NORMAL FINDINGS

### A) Cardiac volume

This is an important parameter but difficult to calculate and of relative value. It should be compared with other paraclinical examinations. The large number of methods available indicates that none is totally satisfactory. We will mention only three such methods.

(1) The cardiothoracic index:
is obtained on a frontal chest film by dividing the maximum transverse cardiac diameter by the maximum transverse thoracic diameter.
This ratio is always less than or equal to 50%

(2) The cardiac surface area
is calculated in a frontal position from the following equation:

$$S = \frac{KxLxl}{4} \quad \text{(figure 2)}$$

S is expressed in cm2
K is the magnification factor

"L" is the longest diameter of the heart (about 12 to 15 cm in adults) between the apex of the heart and the junction between the right atrium and the superior vena cava (point D).

"l" is the short diameter of the heart between the right cardiophrenic angle at the junction between the left ventricle and the trunk of the pulmonary artery (point G')

The surface area of the heart is usually expressed relative to the body area deduced from tables giving the body weight and height of the subject: the normal area of the heart ranges between 56 and 76 cm2/m2.

(3) The heart volume: (figures 2 and 3). V = KxLxlxd
involves a new parameter "d", the antero-posterior diameter of the heart which, in the *lateral position, is the length of the horizontal line between the most anterior point* and the most posterior point on the heart silhouette.

The volume is also expressed relative to the body surface area and should be less than 540 ml/m2.

### B) Normal cardiovascular silhouette

The four positions teleroentgenograph of the heart with barium opacification of the oesophagus distinguishes the four cardiac cavities.

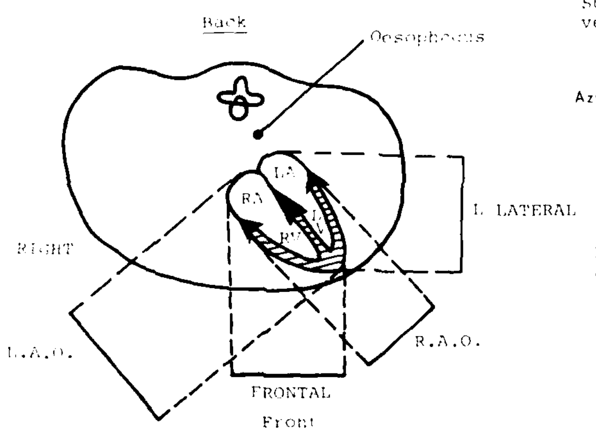



Figure 1. Axial position

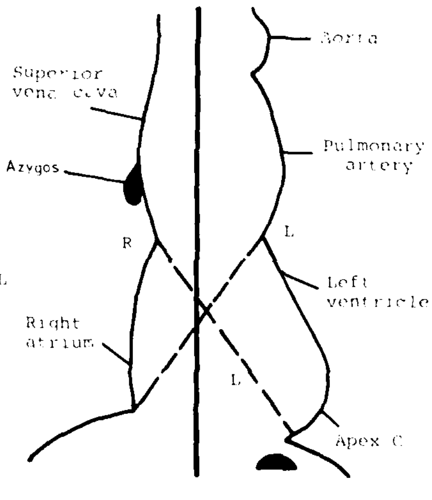
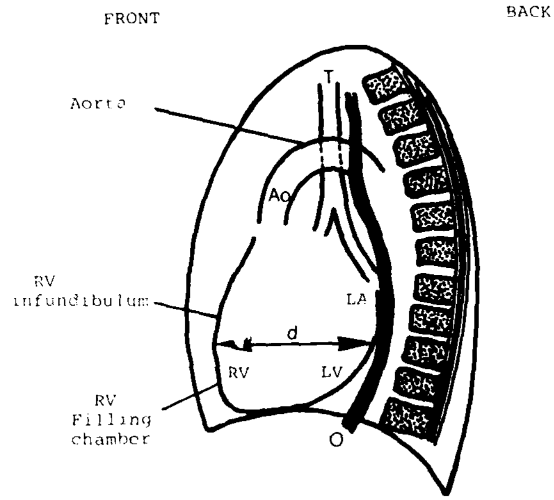



Figure 2. Frontal position

| | | | |
|---|---|---|---|
| Right border : | Superior arch | : | Superior venacava extended upwards by the brachio-cephalic trunk |
| | Lower arch | : | Border of the right atrium |
| Left border : | Upper arch | : | Aortic knob |
| | Medium arch | : | Trunk of the pulmonary artery |
| | Lower arch | : | Left border of the left ventricle |
| Upper border : | Ascending aorta | | |
| Lower border : | Inferior venacava | | |
| | Right atrium | | |
| | Right ventricular filling chamber | | |
| | Apex of left ventricle | | |

(B) SIDE VIEW: Figure 3




Anterior border

upper arch : aorta
medium arch : infundibulum
lower arch : right ventricle

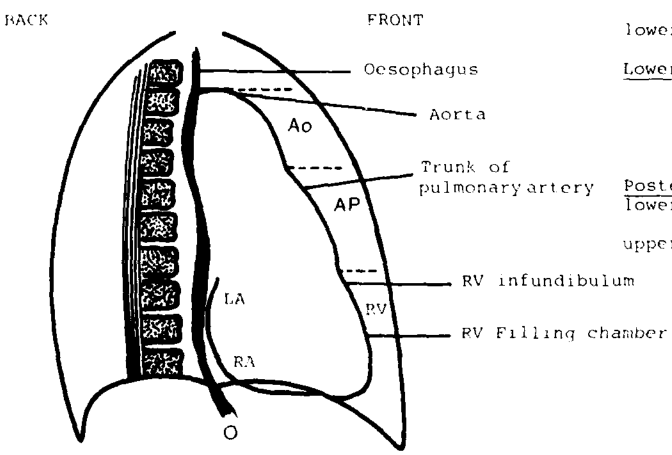
Posterior border

upper arch : vascular with no continuous contours
lower arch
above : posterior contour of the left atrium
below : filling chamber of the left ventricle.

Inferior Vena cava

Upper border : aortic arch
Lower border : superimposed borders of the right and left ventricles not distinguished from the diaphragm.

(C) RIGHT ANTERIOR OBLIQUE (50°) : figure 4
TRUE FRONTAL VIEW OF THE HEART



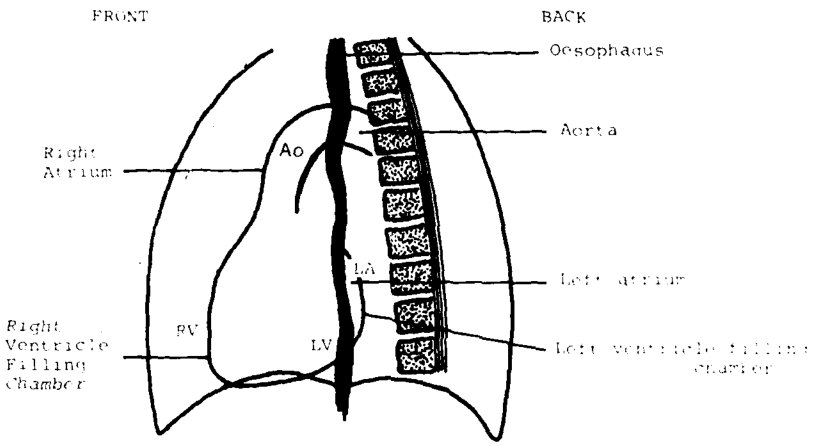

Anterior border
upper arch : ascending aorta
medium arch : trunk of the pulmonary artery
lower arch : right ventricle

Lower border from back to front
inferior vena cava
right atrium
filling chamber of right ventricle.

Posterior border: almost vertical
lower arch : left atrium
right atrium
upper arch : vascular, poorly defined.

(D) LEFT ANTERIOR OBLIQUE (60°) *figure 5*

TRUE SIDE VIEW OF THE HEART
the plane of the interventricular septum is parallel to the X-rays




**Anterior border**

| | | |
|---|---|---|
| Lower arch | : | pumping chamber of the right ventricle |
| Medium arch | : | right atrium |
| Upper arch | : | aorta |

**Posterior border**

| | | |
|---|---|---|
| Upper arch | : | vascular, poorly defined |
| Lower arch | : | remains some distance from the spine |
| corresponds | - | above to the left atrium<br>below to the left ventricle |

(E) THE HILUS AND PULMONARY VASCULARISATION

hilus:

- emergence of the pulmonary arteries when leaving the mediastin
- in 97% of cases, the left hilus is 0.5 to 2 cm higher than the right hilus.

pulmonary vascularisation

- investigation of vascular distribution

(1) The vascularisation is analysed quantitatively at the upper, median and lower zones of the lungs. Normally in the upright position, the base of the lungs receives about double the perfusion of the upper lung. However, in the decubitus position, the blood flow to the upper and lower lungs becomes equal.

(2) The vascularisation is analysed in the hilar region, the median zones and the peripheral zones near the pleura. Normally the vascularisation becomes invisible 2 cm within the periphery.

(F) CONTRIBUTION OF THE DIFFERENT POSITIONS

In practice, although the four basic positions are complementary, they may not always be indispensible. The following table summarises the usefulness of the positions in the identification of the various cavities.

| | frontal | lateral | LAO | RAO |
|---|---|---|---|---|
| RA | ++ | | + | |
| RV | ++ | ++ | + | |
| LA | ++ | ++ | + | ++ |
| LV | ++ | + | + | |

## VARIANTS OF THE X-RAY FILM OF THE NORMAL HEART

a) Heart and thoracic biotype

The appearance of the cardiac silhouette is influenced by the shape of the thorax.

+ the vertical heart in the long thorax:
  - the heart is small, long and narrow, and virtually median in position. The heart appears "droplike".

++ the horizontal heart in the short thorax:
  - in a small subject, often obese. The heart rests on the diaphragm

+++ the heart in thoracic deformation:

i) the heart in straight back:
  . straight back is defined as an absence of dorsal kyphosis.
  . in the frontal incidence the heart seems to be increased in size, and thrown over to the left.
  The apex is low down and near to the axial wall
  The right margin is projected on to the spine

ii) the heart in dorsal kyphosis
  . the heart is viewed from the apex as if in left anterior oblique
  . the lower part of the heart cannot be distinguished from the opacity of the diaphragm

iii) the heart in dorsal scoliosis
  . dorsal scoliosis produces deformation of the rib cage and affects the shape of the cardiac silhouette
  . in general the heart is situated in the concavity of the scoliosis.
  . in the frontal film it is right anterior oblique in scoliosis with right convexity and left anterior oblique in scoliosis with left convexity.

iv) the heart in "funnel" thorax:
  . the mass of the heart is compressed within the rib cage and rotated into a slightly right anterior oblique position :
  the size of the heart appears to be increased
  . the position of the silhouette assesses the extent of sternal depression.

b) Physiological factors affecting the shape and size of the heart

When the diaphragm descends during inspiration, the heart becomes vertical and appears smaller. This situation is reversed during expiration.
Any process affecting the position of the diaphragm alters the appearance of the cardiac silhouette.

c) Athletes heart

raises the question of the isolated enlarged heart which may take two forms:
- globular heart:
  vertical and symmetrical positioning of the heart
- "left" heart:
  appearance of left ventricular hypertrophy with a cardiothoracic index at the upper limit of normal.

d) African heart

The examining expert may sometimes encounter an asymptomatic heart with a cardiothoracic index at the upper limit of normal.

Apart from this index, the shape and haemodynamic features of the heart are normal. Complementary examinations should be carried out to exclude incipient primitive myocardiopathy and to confirm the athlete's heart or "idiopathic" cardiomegaly, frequently found in the tropics.

## IV THE DISEASED HEART

We shall discuss only minor abnormalities such as are actually found during examinations for the fitness of flying personnel.

(1) Congenital heart disorders

Some may be well tolerated and so encountered during examinations of personnel. Radiology may provide the expert with very valuable diagnostic information:

- interatrial communication
  . slight dilatation because of overloading of the right cavity and of the trunk of the pulmonary artery which presents marked and significant systolic expansion when viewed on televised fluoroscopy.
  . the left cavities are normal
  . there is pulmonary hypervasculisation due to excessive supply (shunt).

- nterventricular communication
  . slight hypertrophy of the left cavities
  . right cavities unaffected
  . pulmonary hypervascularisation

- coarctation of the aorta characterised by:
  . unfurling of the aortic arch to a "3" shape (visible in frontal and left anterior oblique films) or variants of this, the cause of which may not be evident.
  . signs of left ventricular hypertrophy
  . later, the typical costal nicks become visible on the posterior arches of the first ribs.

(2) Acquired valvular heart disease

- 4-position teleroentgenography detects any increase in one or more of the cardiac cavities. With other exploratory methods, it can be used to investigate the pulmonary and cardiac effects of valvular disease.

- televised fluoroscopy
investigates the kinetic features of the various cavities.
detects calcification of mitro-aortic orifices and investigates their appearance, site and mobility.
This study is carried out in frontal, lateral and slightly right anterior oblique positions.

It should be recalled that mitral calcifications are projected within the postero-lateral region of the cardiac mass. They rise during diastole and fall during systole. Aortic calcifications are in a higher and more anterior site than mitral ones.

Mitral calcifications move in a horizontal plane whereas aortic calcifications move in a vertical plane or a more complex movement described as "dancing". The amplitude of the movement varies between 0.5 and 1 cm.

(3) Ischaemic heart disease

The usual X-ray examination method does not normally provide any helpful information. Televised fluoroscopy, possibly with video recording, is of great value in the diagnosis of parietal aneurism.

(4) Obstructive cardiomyopathy

- often poses problems of diagnosis and fitness to the expert physician.
- standard X-ray may often be normal, but may present :
  . moderate cardiomegaly of the left ventricle
  . the virtually universal absence of dilatation of the ascending aorta.

- televised fluoroscopy confirms the absence of calcification of the aortic valves but diagnosis of obstructive cardiomyopathy is based above all on echocardiography. The indications for this technique conti·ie to expand and the method has also revolutionised the diagnosis of mild pericardial effusion.

## CONCLUSION

In the cardiological assessment of an expert examination of flying personnel, four-position teleroentgenography and televised fluoroscopy remain the usual methods for the analysis and kinetic investigation of the cardiovascular silhouette and pulmonary vascularisation.

But this examination, which was previously the fundamental if not the only method, is now part of a battery of complementary tests in an up to date investigation intended to provide even greater reliability in the assessment of fitness for flying of flying personnel.

## SHORT BIBLIOGRAPHY

1 - P. BRET, M. AMIEL
Etude du coeur normal en radiologie standard
F.P.U. 1979 - Journée nationale de radiologie .

2 - A. BONNEMAZOU et J. CHERMET
Méthodes d'examen, sans opacification des lumières cardio-vasculaires
E.M.C. 1975 - 32005 A. 10

3 - J.F. SOURIAU - J.C. HOEFFEL
Le coeur normal .
feuillets d'électro-radiologie N° 113.
Sept.-Oct. 1979.

CHAPTER 6

# CONTRIBUTION OF CARDIAC MECHANOGRAMS IN THE EXPERT EXAMINATION OF FLYING PERSONNEL

by R.Carré*, R.Amoretti ***, A. Didier** and H. Ille**

## I - INTRODUCTION

The idea of graphical recording of carotid pulsations of the apexogram is not recent but had already been carried out in the 19th century by CHAVEAU, MAREY and MACKENZY. However, although these recordings were valuable to physiologists, they were of little practical use to the clinician. It is the possibility of transforming the phenomena under study into inertia-free electrical changes which has made it possible to return to the mechanogram and use it to provide information useful to the clinician and to experts examining flying personnel.

These are non-invasive methods which are easily reproducible at each examination. They also provide recordings which can be added to the pilot's medical record and compared from one examination to another.

Cardiac mechanograms provide three types of information:

1) Analysis of cardiac murmurs, determining the type of heart disease on the basis of phonocardiography,

2) Study of atrial distension from the carotid pulse cardiogram,

3) Chronocardiographic determinations based on the systolic time intervals which give some idea of the contraction of the myocardial muscle.

## II - ANALYSIS OF CARDIAC MURMURS

Heart auscultation and complementary examinations with the electrocardiogram and cardiac X-ray can establish the organic nature of a diastolic murmur and in most cases can determine the presence or absence of an organic cause of systolic murmur. In some cases, it may be helpful to use the non-invasive method of cardiac mechanogram. The mechanographic methods used in the authors' unit are as follows:

a) Phonocardiogram with 4 channels (35 [illegible] 70 Hz, 140 Hz, 280 Hz) taken from the auscultation of the systolic murmur;

b) The study of the carotid pulse involves two facets:

- study of the shape of the recording
- study of the time sequence of the various events, ascension time, 1/2 ascension time and duration of the left ventricular ejection.

However, these times must be corrected in function of the heart rate using the PERNOD and CARRE grid.

c) Apex and Jugular cardiogram

d) Dynamic tests involving :

1 - the Valsalva manoeuvre, which can determine whether the systolic murmur is of left or right origin. A murmur of right origin reaches maximum intensity at the end of the test whereas in the case of a murmur of left origin, the peak is reached only 5 systoles after halting of the test.

2 - Pharmacodynamic tests involving recording following the amyl nitrite or isuprel test followed by tests with vasopressors (aramines, methoxamine).

Hence the recordings obtained make it possible to determine whether the murmur is due to an obstruction or to regurgitation and whether it is right or left.

* Médecin Chef des Services
** Médecins en Chef
*** Médecin Attaché des Hôpitaux Périphériques
Centre Principal d'Expertise médicale du Personnel Navigant de l'Aéronautique
26 boulevard Victor 75996 PARIS ARMEES FRANCE.

| | ANTEGRADE OR OBSTRUCTION MURMUR | RETROGRADE OR REGURGITATION MURMUR |
|---|---|---|
| Shape | diamond shaped | rectangular |
| Time sequence | emerges at S 1<br>does not reach S2 | holosystolic<br>extends from S1 to S2 |
| After extrasystolic pause | strengthened | not strengthened |
| Amyl nitrite | strengthened | reduced |
| Isuprel | strengthened | reduced |
| Aramine or methoxamine | reduced | increased |

We will now consider the various types of systolic murmur which may be detected during admission or review examinations.

A - Nonpathological murmurs

In the expert examination of flying personnel, it is extremely important to be able to assert the non-pathological nature of a systolic murmur and to classify it. It is essential in the expert examination that any systolic murmur should be recorded on the mechanogram and the tracing kept as medicolegal evidence.

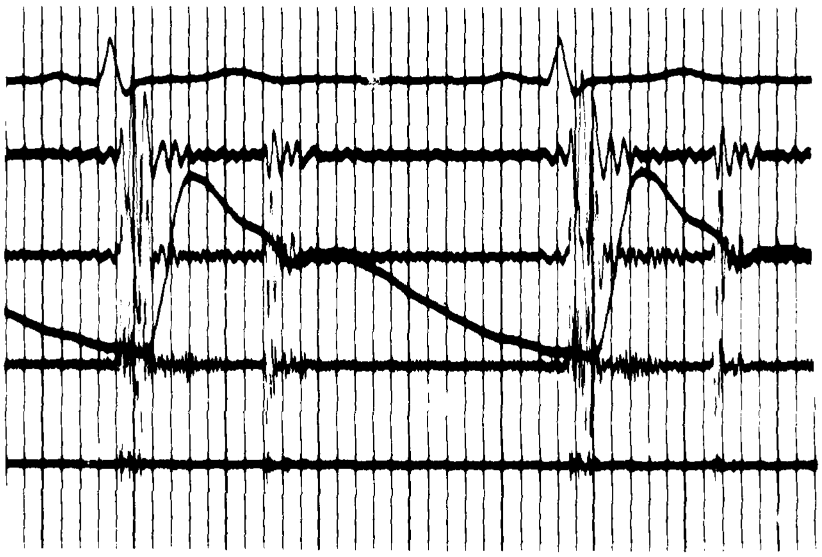


Figure 1

Non-organic infundibulopulmonary murmur
Male, 21 years
Normal mechanogram.

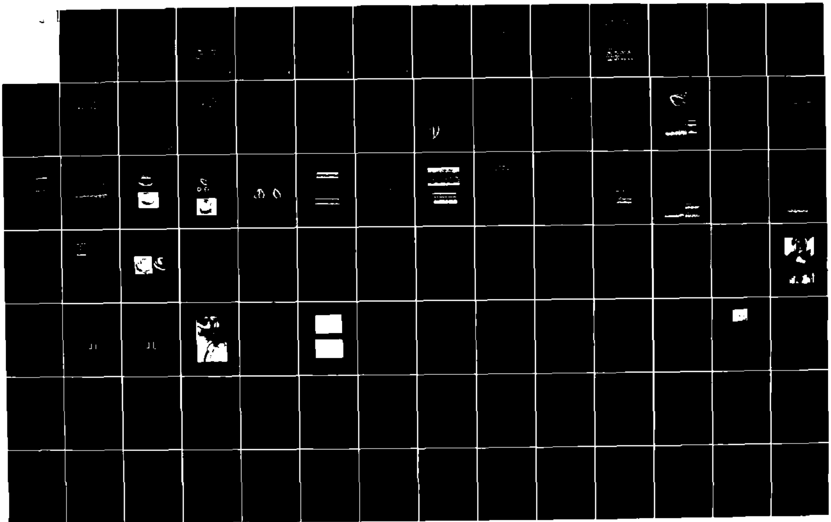
1 - NON-PATHOLOGICAL MURMUR

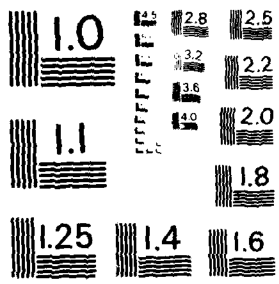
A non-pathological murmur is a murmur which may or may not be produced by some anatomical abnormality but the development of which remains non-pathological. The murmur must therefore have no pathological haemodynamic effects and no such effects must develop.

The importance of the investigation of such murmurs results from their high incidence, particularly in young subjects, and of the importance of distinguishing them from partial organic murmurs.

AD A138 965 NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE(U) ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT NEUILLY.. R CARRE ET AL. 2/3

UNCLASSIFIED DEC 83 AGARD-AG-277(E) F/G 6/5 NL






MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

a) <u>Non-pathological murmurs arising in the ejection route of the right ventricle</u>

I Mechanism

A murmur may develop when the circulatory speed increases, when the calibre of a vessel increases or becomes irregular, or more secondarily the viscosity of the blood is reduced.

Usually these mechanisms are combined but the determining factor remains the increased speed of circulation in the vessels. This is directly related to the systolic output and inversely related to the peripheral resistance of the circulation.

Since pulmonary resistance is lower than systemic resistance it is easy to see why murmurs arise readily, appear in the pulmonary pathway.

II Various murmurs

1) TRIPIER and DEVIC's infundibulopulmonary murmur

This is the most common.
Static study:

. Protosystolic murmur, persistence of heart sounds (apart from a rapid physiological repeat of S2)

. Site: lungs and the left sternal border

. Moderate intensity, crescendoing during exploration and following exercise, decrescendoing during deep inspiration and in the upright position

. Normal mechanograms

Dynamic investigation: essential in order to eliminate partial organic murmur which may present the same static characteristics:

. Valsalva manoeuvre : reacts like a right murmur, i.e. reappears almost immediately following the end of the manoeuvre.

. Amyl nitrite test : the murmur intensifies, its duration is increased but it peaks earlier, possibly as early as S1 in which case the murmur takes on a triangular form. The shape and time sequence of the carotid pulse remain within normal limits.

This murmur may also occur:

. During conditions characterised by an <u>increase in blood volume</u> or in the speed of circulation: exercise, pregnancy, fever, anaemia, hyperthyroidism, arterio-venous fistula, irritable heart in neurotonic subjects.

. In thoracic deformities: flat back, funnel thorax, kyphoscoliosis; which should not be mistaken for congenital heart disease.

2) STILL's musical murmur

Occurs in the infant (2 to 4 years)

Characteristics: regular groups of low or high frequency oscillations
Site: left sternal border or endapical.

Responds like infundibulopulmonary murmurs to pharmaco-dynamic tests.

3) Stenosis of the trunk or branches of the pulmonary artery

The murmur is considered non-pathological when the pressure gradient along the pulmonary artery is low, below 15 mm Hg.

Murmur: obstructive type midsystolic, sometimes early-to-midsystolic, with no abnormality of S2;
Site: $2^e$ and $3^e$ left intercostal spaces, radiating into the armpit and the omovertebral space;
Intensity usually high
Normal mechanograms.

Amyl nitrite test: the intensity and duration increase, but most notably the vibrations peak moves away from S1 and the murmur becomes late systolic and may go beyond A2, it takes on the appearance of an extremely late holo-systolic murmur. Methoxamine reduces the murmur.

b) <u>"Left" non-pathological murmur</u>

This is less frequent and more difficult to distinguish from an organic lesion such as aortic bicuspidy.

The phonocardiographic signs are similar to those of the "right" murmur apart from the fact that it always begins after the base of the carotid pulse and that it peaks in the aortic area.

c) Cardio-pulmonary murmurs

1) Non-pathological carotid murmur

Frequent in subjects presenting irritable heart.

- Short early-to-mid systolic murmur, carotid site, low intensity, high frequency.
- Ultrasonic Doppler exploration may be required to exclude carotid stenosis.

2) Jugular vein murmur

- In young subjects or those presenting hyperkinesia
- Continuous or partial murmur, subclavicular and right cervical in site, low intensity.
- Reduced or eliminated by turning the head to the right, forced expiration, the Valsalva manoeuvre or compression of the jugular above the site of auscultation.
- Amplified by forced inspiration and by amyl nitrite.

## B - Organic systolic murmurs

I - Obstructive myocardiopathy

The major concern of the expert in his examination of flying personnel is the possibility of failing to recognise obstructive myocardiopathy because of the danger of sudden death which this carries.

Obstructive cardiomyopathy constitutes a dynamic obstacle to the ejection of blood from the left ventricle into the aorta. It arises because of hypertrophy of the intraventricular septum.

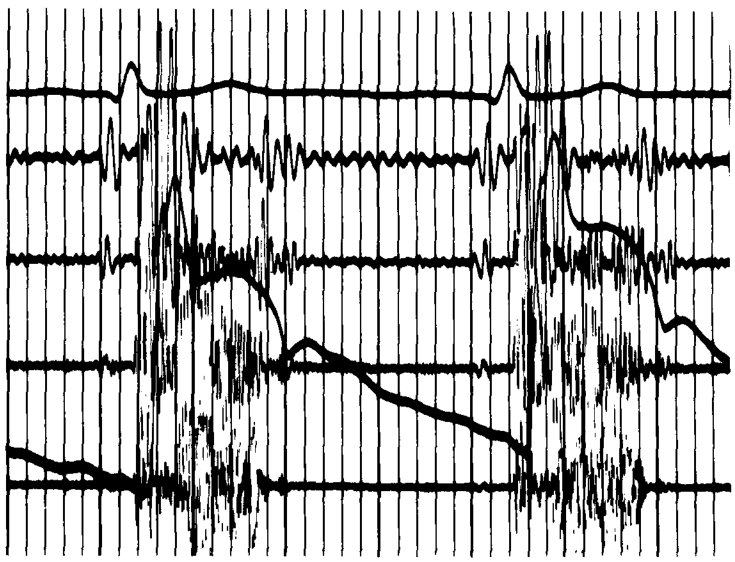


Figure 2
OMC

Male 62 years
Obstructive systolic murmur
S 4
Cardiogram with "Bulge".

a) Diagnosis of OMC

I) Static exploration

1) heart sounds

- S 1 : normal
- S 2 : normal
- S 3 : variable
- S 4 : constant of variable extent
- No systolic ejection click.

2) murmurs

a) Obstructive systolic murmur

- This murmur is produced by hindrance of the ejection of blood from the left ventricle to the aorta due to bulging of the interventricular septum into the pumping chamber at the left ventricle, during systole, thereby resulting in a dynamic obstacle.
- Description:
  . Usually midsystolic murmur, diamond shaped, obstructive: begins after S1 and ends before S2; the murmur peak is late, as compared with that of RA).
  . The murmur may be early-systolic in the basal state or almost holo-systolic leaving a very short interval between S1 and the beginning of the murmur and between the end of the murmur and S2.
  . The murmur may vary on a single recording with several "peaks".
  . In general, a wide variety of shapes of the murmur should be noted, the most typical, however being midsystolic murmur.
- Site: left sternal border or endapical, there may be radiations towards the base and the tip.
- Frequency: recorded particularly at high frequencies.
- Intensity: very variable from very weak to very intense; increases after long diastoles (ventricular extrasystoles and atrial fibrillation)

b) systolic regurgitation murmur

- Murmur related to dysfunction of the leaflets of the large mitral valve; variable
- Holo-systolic murmur, or more frequently late systolic, extending to S2 (which distinguishes it from an obstruction murmur).
- Site: maximum at the apex, possibly with some radiation to the armpit.

3) carotid pulse

a) shape

- Varies widely from one subject to another and in a given subject depending on the conditions of examination and even the position of the subject.
- The most usual configuration is the tracing known as the COBLENCE type 3 tracing, i.e. the normal tracing by far the most frequent in incipient OMC.
- But there is a typical tracing, encountered especially in developed forms and this is the type 1 or "bulge" shape: the first peak is very early, pointed and precedes the peak systolic sound; it is followed by a dip the depth of which may vary, the descending slope of which occurs at the same time as the maximum systolic murmur; this is followed by a second peak which is not so high. The catacrotic wave is very low and followed by an enlarged dicrotic wave.

  Type 2 is less frequently detected and less characteristic: an early peak followed by a concave descending section, ending with a very low catacrotic notch which in turn is followed by a very large dicrotic wave.

b) time sequence

- Corrected ejection time: variable, usually normal or prolonged (especially in type 1).
- Ascension time: reduced (between 0.06 and 0.09 s).
- Semi-ascension time: normal but somewhat short (which differentiates from RA)

4) apex cardiogram

- normal diastolic slope with a characteristic marked A wave, at the same time as S4.
- systolic wave of variable configuration: usually normal, particularly in incipient OMC

Sometimes the appearance may be similar to Type I of the carotid pulse with a first early pointed peak followed by a trough during maximum systolic murmur and then a second peak of variable height.

5) jugular pulse

- usually normal
- sometimes there may be an enlarged "a" wave, or a notch on the rise following the "x" trough.

II - Dynamic study

Pharmaco-dynamic studies are of particular diagnostic value in OMC

1) respiratory manoeuvres : Valsalva manoeuvre

- This is a "left" murmur, and so occurs only 4 to 5 beats after the end of the manoeuvre.

- Furthermore, unlike other murmurs, the OMC murmur is not reduced during the apnoea phase and may even tend to increase.

2) Pharmaco-dynamic tests

a) amyl nitrite tests

- amyl nitrite increases obstruction murmurs and so increases both the intensity and duration of the OMC murmur.
- in cases of mild murmur in the basal state, there may be an "explosion" of the murmur which becomes almost holo-systolic, but does leave a free interval between S1 and the beginning of the murmur (which distinguishes it from the infundibulo-pulmonary murmur ) and between the end of the murmur and S2 (which distinguishes it from stenosis of pulmonary artery branches).
- The shape of the carotid pulse and apexcardiogram may also be altered; tracings which are normal in the basal state may take on the appearance of type I or II and become characteristic.
- Corrected ejection time of the carotid pulse cardiogram is also increased even if normal in the basal condition.
- The A wave of the apex cardiogram is amplified (as is S4).
- It should be stressed that the carotid pulse or the apex cardiogram may take on the characteristic appearance of Type I following a long diastole (after an extrasystole or during atrial fibrillation for example).

b) methoxamine test

- obstruction murmur or any accompanying mitral leakage reduce intensity, especially in late systole and may even disappear.
- the carotid pulse loses its typical appearance under this drug.

III - Time intervals

- QS1 : normal
- QA2 : generally prolonged

OVERALL, the diagnostic criteria for OMC are as follows:

- a midsystolic obstruction murmur, increasing markedly with amyl nitrite, but always remaining distinct from S1 and S2, and with the peak murmur always following the first peak of the carotid pulse or apex cardiogram.
- S4 and a marked A wave on the apex cardiogram reflect the obstruction.
- the carotid pulse and apex cardiogram may not always have the typical shape when there is a type 1 Coblence, with a first peak always preceding the maximum systolic murmur.
- with regard to the timing, the increase of the corrected ejection time, particularly with amyl nitrate, and the reduction of the time of ascent of the carotid pulse are two concordant signs of great significance.

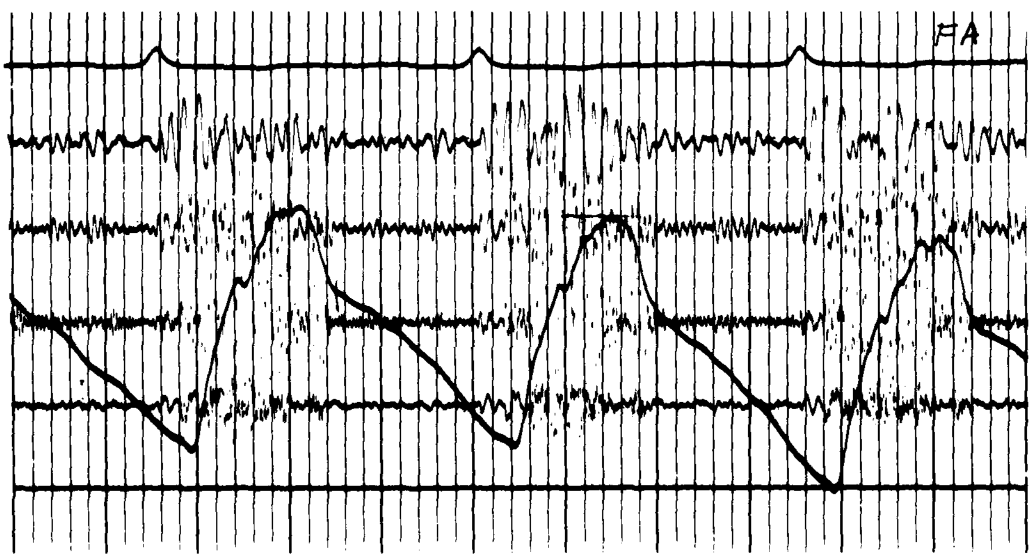



**Figure 3**
**Typical mechanogram in aortic stenosis**

## 2 - AORTIC STENOSIS

Aortic stenosis (AS) is an obstacle to ejection from the left ventricle. It is easily diagnosed both clinically and using a phonomechanograph but what is important is to establish the extent of stenosis in order to guide therapeutic indications.

A) Confirmation of the diagnosis of AS at the orifice

I - Static investigation

1) heart sounds

- S1 : normal or reduced
- S2 : normal or reduced
- S3 : variable
- S4 : frequent.
- Frequent early-systolic ejection click; High frequency sound, of fairly short duration (less than 0.04 s), at the foot of the rising branch of the carotid pulse cardiogram.

2) systolic murmur

- obstruction midsystolic murmur, diamond shaped, arising away from S1, and not extending to the aortic component of S2; the beginning of the murmur is simultaneous with the foot of the carotid pulse.
- Site: maximum at the aortic focus, radiating into the vessels of the neck, but sometimes maximum along the left sternal border.
- Better recorded at high frequencies
- Intensity increased after long diastoles

3) carotid pulse cardiogram

a) shape

- There are two characteristic features
- The slowing of the rising branch, resulting in an anacrotic notch, with the appearance of a vibrating plateau at the end of the rise.
  . Catacrotic notch not prominent, followed by a dampened dicrotic wave.

b) timing

- Prolonged corrected ejection time
- Prolonged semi-ascension time (above 0.05 s).

4) apex cardiogram

- The important feature is the presence of an A wave
- The systolic curve varies, sometimes there is a slow rising branch suggesting the anacrotic nature of the carotid pulse with a second peak higher than the first.

5) jugular cardiogram

- Normal apart from a damping of the "c" feature and possible undulations of the trough "x".

II - Dynamic investigation

1) respiratory movements: Valsalva manoeuvre

- This is a "left" murmur and hence does not reappear until 4 or 5 pulsations after the end of the manoeuvre.

2) pharmaco-dynamic tests

a) amyl nitrite test

- The systolic murmur increases in intensity and duration
- The ejection time of the carotid pulse cardiogram is only slightly reduced, confirming the presence of a fixed obstacle.
- In practice, this method is of little use, in the diagnosis of AS.

b) methoxamine test

- This results in reduced intensity of the systolic murmur and releases the end systole.

III - Time intervals

- QS1 interval : normal
- QA2 interval : prolonged
- PEP/e-i ratio : reduced

B) Assessment of the degree of stenosis

I - The various criteria

1) heart sounds

- S1 is normal in incipient AS; it is reduced in intensity as the stenosis develops and is barely detectable in very severe stenosis.

- S2 in particular becomes less intense and may even disappear, not in relation to the degree of stenosis but of the extent of the semilunar calcifications.

  In very severe AS, PS tends to draw near to A2 and may even combine with it to produce a paradoxical outburst at S2. At a more severe stage, P2 may precede A2 and produce a paradoxical double S2.

- S4 : most authors consider the presence of this sign as a sign of severe stenosis
- Early-systolic click: occurs in moderately severe stenoses; tends to disappear in severe stenoses.

2) Systolic murmur

- The intensity of the murmur is not proportional to the degree of stenosis.
- During systole, the later the peak of the maximum murmur and the nearer the end of the murmur to S2, the more severe the stenosis.
- It should be noted that in highly calcified AS there may be an accompanying diastolic murmur.

3) Carotid pulse cardiogram

- The configuration does not indicate the degree of stenosis.
- The timing is of greater importance here
  - . The semi-ascension time is longer the more severe the stenosis: between 0.05 and 0.14 s.
  - . A rate-corrected ejection time greater than 120% (or 0.34 s) indicates severe AS;
    - = this time interval is of no significance unless associated mitral disorders (which would tend to reduce it) are absent
    - = it is a useful feature to monitor development of the stenosis;
    - = it returns to normal following surgical operation

4) Apex cardiogram

- The diastolic slope is normal initially. As the stenosis increases, an A wave appears simultaneously with S4, and the F wave fades progressively.
- The systolic tracing is normal in mild SA and in severe SA presents an anacrotic notch as in the development of the carotid pulse.

IN ALL, 5 criteria of severity are available:

1 - reduction of S1;
2 - presence of S4 and a prominent A wave on the apex cardiogram;
3 - late systolic murmur;
4 - extended corrected ejection time
5 - extended semi-ascension time

II - Classification in function of the degree of stenosis

1) mild AS

- little or no change in heart sounds
- early-systolic murmur, lasting less than 0.20 s, separated from S2 by more than 0.04s, maximum during the first half of the systole;
- on the carotid pulse cardiogram: semi-ascension time less than 0.07 s, normal ejection time.
- apex cardiogram normal.

2) severe AS

- changes in S2
- frequent early-systolic click, followed by maximum midsystolic murmur;
- Carotid pulse cardiogram: lengthening of the semi-ascension time to 0.07 s or more , and of the corrected ejection time to between 110 and 120%

3 **MITRAL DEFECT**

Mitral defect results in a reflux of the blood from the left ventricle towards the left atrium during systole, following leaking of the mitral valves.

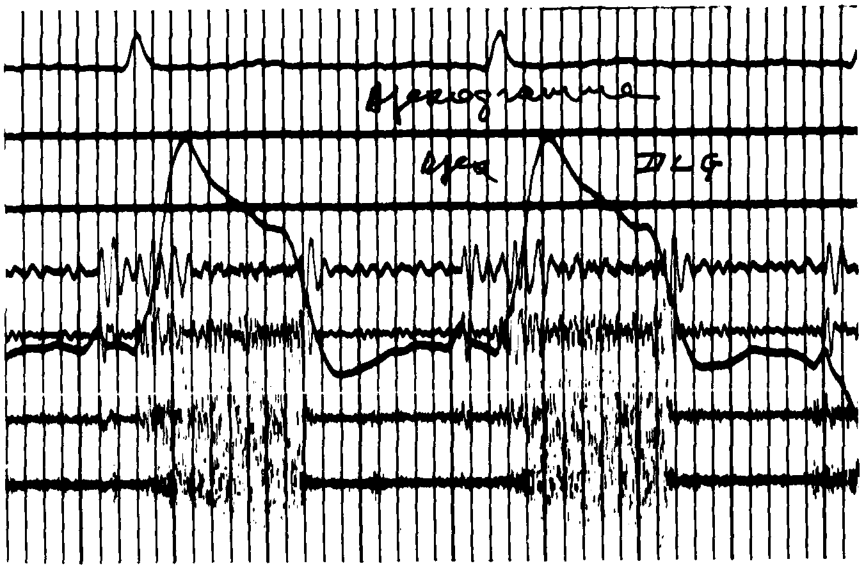


Figure 4. Male 56 years Tracing 2

I - Static investigation

1) heart sounds

- S1 : usually normal, but occasionally exaggerated in severe leakage.
- S2 : usually normal
  . sometimes exaggerated in hypertension;
  . may be doubled, sign of severe leakage.
- S3 : absent in moderate forms; this is a highly characteristic sign of major leakage, and may be of greater intensity than the heart sounds.
- S4 : variable
- Mitral opening click (MOC): fairly frequent in severe leakage, debatable significance.

2) murmurs

a) systolic murmur

- Constant regurgitation type;
- Begins at S1;
- Holo-systolic in moderate and severe leakage, ending after A2;
- In slight leakage, the murmur is partial: early to midsystolic, mid to late systolic or simply end systolic;
- Site: in general at the apex, radiating towards the armpit; but it may be detected up to the aortic focus and even predominate there;
- The murmur is best recorded at high frequencies;
- The intensity is not proportional to the degree of leakage.

b) diastolic rumble

- This is a functional AS rumble;
- It begins at S3 or at MOC;
- It is a brief rumble, when recorded at MOC frequency;
- Site: at the apex;
- Moderate intensity;
- Appears in severe incompetence

3) carotid pulse cardiogram

a) configuration

- Normal in moderate incompetence;
- In severe incompetence there is a low sited catacrotic notch with a wide dicrotic wave, producing a double isosceles triangle shape ( low output type);

b) timing

- Rate-corrected ejection time normal in mild incompetence, reduced in severe incompetence;
- 1/2 ascension time normal;

4) apex cardiogram

- Normal in incipient MR;
- In severe incompetence, it undergoes characteristic changes:
  . large pointed symmetric (variable) F wave;
  . wide L wave in MR due to torn chordae;
  . systolic pattern normal or pointed.

5) jugular cardiogram

- Normal

6) Oesophageal cardiogram

- A vibrating plateau configuration between the "x" trough and the "v" wave.

7) In summary, criteria of severity:

- Holo-systolic murmur;
- Accompanying diastolic rumble;
- Accentuation of S1 and S2;
- An intense and early S3
- Carotid pulse in the form of a double isosceles cardiogram with a reduced ejection time;
- Apex cardiogram: wide pointed and early F wave.

II - Dynamic Investigation

1) respiratory *manoeuvres*: Valsalva *maneouvre*

- This is a"left" murmur and so does not reappear until 4 or 5 pulsations after the end of the manoeuvre.

2) pharmaco-dynamic tests

a) amyl nitrite test

- Produces *a reduction in the regurgitation systolic murmur which is particularly* clear in the late systolic period;
- Produces a reduction in the accompanying diastolic rumble where there is one (reacts like a *regurgitation murmur*);
- This test can therefore exclude any associated organic AS.

b) *methoxamine test*

- Inversely this increases systolic murmur and transforms partial murmur into a holo-systolic murmur.
- The major effect is to reveal or accentuate the late systolic component of systolic murmur.

*III - Time intervals*

- QS1 : normal (increased in massive incompetence)
- QA2 : increased in severe incompetence
- PEC 1 interval : prolonged
- PEC 2 interval : prolonged
- Pre-ejection period (PEP) : prolonged.

4 - PULMONARY STENOSIS

Pulmonary stenosis constitutes an obstacle to the ejection of blood from the right ventricle into the pulmonary artery. This is an essentially congenital valve disorder.

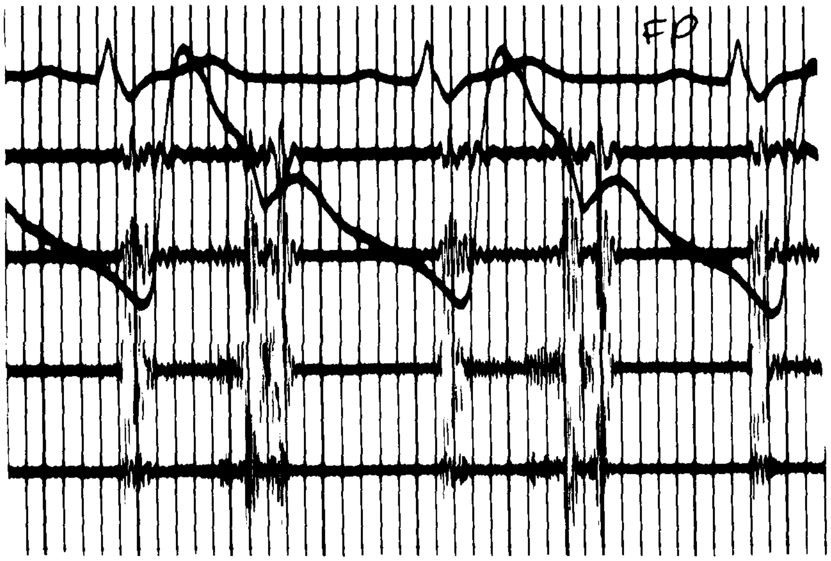



Figure 5

Male: 19 years    Tracing 1
Late systolic murmur clearly localised at the pulmonary focus, markedly increased by AN (Tracing 2). Fixed doubling at S2 with accentuation of the pulmonary component.

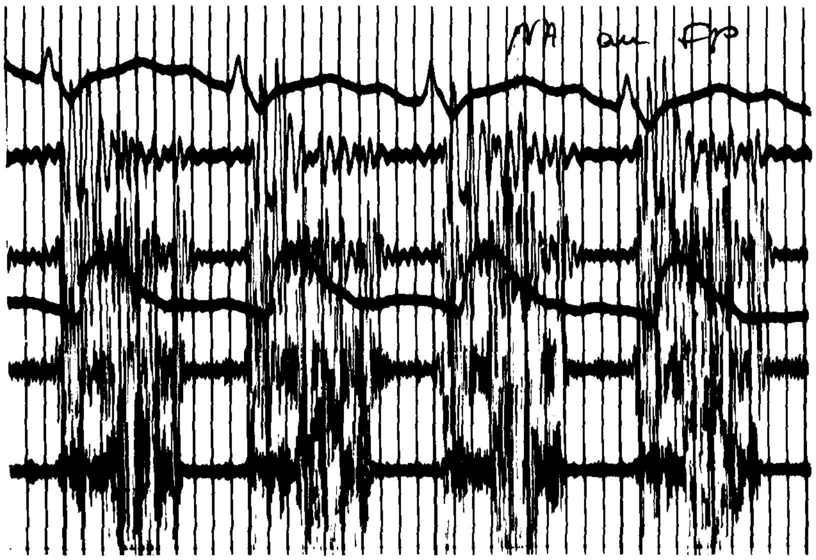



Figure 5 b

Pharmaco-dynamic test showing the increase of the end-systolic murmur due to pulmonary stenosis.

A) Confirmation of the diagnosis of valvular PS.

I - Static investigation

1) Heart sounds

- S1 : normal
- S2 : characteristic changes: Doubling at S2 because of delayed P2
  Reduced intensity of P2
- S3 : variable and of no pathological significance in the young subject
- S4 : variable
- Early-systolic click: High frequency sound, short duration;
  Recorded at the pulmonary focus during exploration;
  Combined with S1 .

2) Systolic murmur

- Obstruction murmur, beginning at S1 or at the click, midsystolic, slowly rising, ending at a variable distance from S2;
- Site: pulmonary focus;
- Intensity variable, often severe;
- Recorded at moderate or high frequency.

3) Carotid pulse cardiogram

- Normal

4) Apex cardiogram

- usually normal, sometimes slow systolic rise or even a prominent A wave.

5) Jugular cardiogram

- "a" wave normal or wide;
- "y" depression normal;
- P2-v interval shortened.

II - Dynamic investigation

1) respiratory manoeuvres

a) inspiration - expiration

- Theoretically the PS murmur increases during inspiration and decreases during expiration.
- This manoeuvre may sometimes distinguish between a mild PS and a mild AS.

b) Valsalva manoeuvre

- This is a "right" murmur and so reappears almost immediately at the end of the manoeuvre.

2) pharmaco-dynamic tests

a) amyl nitrite test

- The systolic murmur increases in line with the intensity, but late (in late systole) and may encompass A2.

b) methoxamine test

- Reduces the intensity of the murmur, especially in late systole.

III - Time Intervals

- Left time sequence normal
- Right ejection time increased, but not detectable.

5 - AORTIC COARCTATION

Aortic coarctation is equivalent to a stenosis at the beginning of the descending aorta, producing a distal obstacle to the ejection of blood from the left ventricle into the peripheral arteries.

SUMMARY OF DIAGNOSTIC FEATURES

- Early systolic click;
- Early to midsystolic obstruction murmur which may last beyond A2;
- Femoral pulse abnormally delayed relative to the carotid pulse.

I - Static investigation

1) Heart sounds

- S1 : normal
- S2 : A2 often accentuated
- S3 : absent
- S4 : variable, related to hypertension
- Ejection early-systolic click frequent, at the aortic focus.

2) Murmurs

a) Systolic coarctation murmur

- Early or mid systolic coarctation murmur begins away from S1, and reaches or may even extend beyond S2;
- In severe forms, the murmur may last right through to mid-di ole, producing a systolo-diastolic murmur;
- Site: left parasternal, but often also in the back, alon e scapula;
- Moderate intensity, in contrast with the very extensive si

b) Associated systolic murmurs

- Often an early systolic murmur is recorded at the aortic f s ue to an AS which may be functional or organic and congenital;
- Less commonly, a congenital MR or VSD murmur may be detected at the apex;

c) Diastolic murmurs

- Sometimes a pre-diastolic AR murmur is detected at the pulmonary focus: This may be either functional or organic and congenital.
- Occasionally, an MR rumble may be detected at the apex: this may be functional or organic and congenital.

d) Systolo-diastolic murmur

- Apart from severe coarctation, the murmur may be due to the persistance of the ductus-arteriosis

To conclude, the most common form is the partial and isolated systolic murmur

3) Carotid pulse

- Usually normal; sometimes with a lobster claw shape with a high 2nd peak
- Timing: corrected ejection time prolonged and 1/2 ascension time normal.

4) Recording of the femoral pulse

- Very useful: This presents an abnormally late beginning and peak as compared with those of the carotid pulse. The more severe the stenosis the greater this delay (greater than 0.09 s); the femoral crest occurs before the catacrotic notch of the carotid pulse cardiogram (instead of after it).

5) Apex and jugular cardiogram: normal

II - Dynamic investigation

1) Amyl nitrite test

- The systolic coarctation murmur increases in intensity and duration like all obstruction murmurs.

2) Methoxamine test

- The intensity and duration of the murmur are reduced.
- The test may reveal an associated MR, AR or VSD .

6 - ATRIAL SEPTAL DEFECT

Atrial septal defect (ASD) is an abnormal communication between the two atria resulting in a left-right shunt. It is a congenital condition.

Figure 6

Mild atrial septal defect
Midsystolic murmur with double S2

I - Static investigation

1) Heart sounds

- S1 : S1 doubled: variable , no diagnostic value
  Intensity increased: variable, (a sign of considerable flow in the shunt)
- S2 : S2 doubled: regular and large, generally 0.04 to 0.06 s;
  Intensity of P2 : normal or increased (in pulmonary hypertension).
- S3 and S4 : variable
- Early systolic click: variable, more frequent and more intense if there is pulmonary hypertension.

2) Systolic murmur

- Early to midsystolic obstruction murmur, often mild, separated from S1 but may extend to A2;
- Site: maximum at pulmonary focus, often radiating towards the apex;
- Recorded in moderate and high frequencies;
- No correlation between the intensity or shape of the murmur and the extent of the shunt.

3) Diastolic signs

- Early diastolic tricuspid opening click, difficult to differentiate from S3, simultaneous with the "v" wave of the jugular venous pulse: variable .
- Functional TR rumble, simultaneous with the "y" wave of the jugular venous pulse: occurs in major shunts: variable
- Early diastolic functional ?? murmur, in cases of clear pulmonary hypertension (Graham Steell murmur): variable

4) Carotid pulse : normal

5) Apex cardiogram

- Normal sometimes with a prominent A wave

6) Jugular cardiogram

- "v" wave greater than "a" wave: variable, with the a/v ratio less than 1.
- "a" wave prominent in pulmonary hypertension.

II - Dynamic investigation

1) Valsalva manoeuvre

- ASD reacts like a "right" murmur, and therefore reappears almost immediately following the end of the manoeuvre.

2) Pharmaco-dynamic tests

a) Amyl nitrite test

- The response is variable, the systolic murmur is usually increased.

b) Methoxamine test

- The response is variable.

III - Assessment of the extent of the shunt

1) Suggesting a minor shunt
- Tightly grouped, doubled S2 (less than 0.05 s): but variable
- No diastolic signs,no S3 and no S4.

2) Suggesting a major shunt
- More frequent doubling of S1
- Presence of one or more diastolic signs, of S3, of S4.

IV - Assessment of the extent of pulmonary hypertension

Suggesting considerable pulmonary hypertension:
- reduced doubling of S2, possibly even fused with a large P2;
- frequent early-systolic click;
- intensity and duration of systolic murmur reduced ;
- jugular venous pulse: large "a" wave and prolonged P2-v interval ;
- sometimes functional RP murmur.

V - *ASD anatomy*

1) Distinction between ostium primum - ostium secundum
- Cannot be distinguished by phono-mechanographic methods.

2) ASD plus RP
- Wide doubled S2, P2 weak or absent;
- Systolic murmur with maximum mid or late systole;
- Short P2-v interval (less than 0.04 s);
- The RP usually dominates the tracing and may completely mask the ASD.

3) ASD plus abnormal pulmonary venous return
- Very difficult to distinguish by phonocardiography.
- The most that can be detected is a fairly variable doubling of S2 with respiration.

4) ASD plus MS: Lutembacher's syndrome
- Very rare; the ASD obliterates the signs of MS.
- The signs to look for are a late diastolic rumble extending to S1, an extended QS , and a continuous murmur at the end apex.

7 - VENTRICULAR SEPTAL DEFECT

Ventricular septal defect (VSD) is an abnormal communication between the two ventricles resulting in a left-right shunt. It is usually congenital.

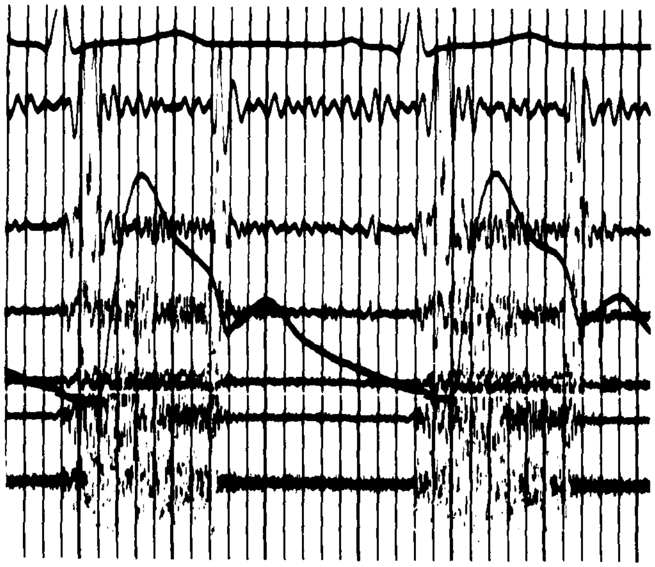


Figure 7

Established VSD recorded at the
right 4th intercostal space

I - Static investigation

1) Heart sounds

- S1: normal or doubled
- S2: Doubling of S2: frequent but variable; tends to disappear in VSD with pulmonary hypertension;
  Accentuation of P2 in function of the extent of the shunt.
- S3 and S4 : variable.

2) Systolic murmur

- Holo-systolic regurgitation murmur, beginning at the first component of S1, may extend beyond A2; may be a midsystolic strengthening; the murmur may be partial;
- Site: left parasternal, radiating throughout the precordial area;
- Recorded at all frequencies .

3) Carotid pulse

- Normal in mild VSD;
- Pronounced catacrotic notch followed by a wide dicrotic wave in major shunt.

4) Apex cardiogram

- Diastolic slope: Wide F wave followed by variable diastolic bulging; A wave not prominent .
- These signs result from left ventricular diastolic overload.

5) Jugular cardiogram: normal

II - Dynamic Investigation

1) Valsalva manoeuvre

- This is a "left" murmur and therefore reappears only 4 to 5 pulsations after the end of the manoeuvre.

2) Pharmaco-dynamic tests

a) Amyl nitrite test

- The intensity of the systolic murmur is reduced especially in end-systole and may encompass S2.

III - Time intervals

- QS 1 and PEC 1 normal (unlike MR) ; however QS1 may be prolonged in major shunts

- Left ventricular ejection time normal or reduced (right ejection time increased, but cannot be determined).

We note that the hearing may frequently be misled when determining the origin of a systolic murmur: the expert examining flying personnel should carry out cardiac mechanograms when faced by any systolic murmur. Such tests make it possible to classify the murmur and in some cases to determine the severity of effects.

| | Infundibular pulmonary murmur | Cardio-pulmonary murmur | AS | OMC | MR | ASD | VSD | PR |
|---|---|---|---|---|---|---|---|---|
| Phono cardiogram | Right Obstruction | Variability | Left Obstruction | Left Obstruction | Regurg-itation | Right Obstruction | Left Regurg-itation | Right Obstruction |
| Carotid pulse cardiogram | N | N | 1) Abnormal shape 2) Abnormal time sequence | Bulge | N | N | N | N |
| Apex cardiogram | N | N | A wave | 1) Bifid 2) A wave | F wave | N | N | N |

We have analysed the mechanograms in systolic murmurs; they are also helpful when investigating the repercussions of diastolic murmur. However, this aspect lies outside the scope of this article on the expert examination.

## III - THE CAROTID PULSE CARDIOGRAM AND ARTERIAL ELASTICITY

It would seem highly interesting to attempt to assess the elasticity of the arterial wall by a physical method such as the carotid pulse cardiogram.

The carotid pulse is recorded using a variable inductance detector. This method is non-invasive easily carried out and easily reproduced at subsequent expert examinations of the flying personnel. The normal carotid cardiogram consists of a rapid rise (pulsion wave) followed by a descent (reflexion wave) ending in the catacrotic notch, which is followed by a second or diacrotic wave.

Two types of change occur with age:
those affecting the configuration and those affecting the I|A ratio.

a) Changes of configuration

With age the shape of the carotid pulse changes, the rise becomes slower and the second systolic crest moves along the descending segment and may even occur after the first peak resulting in an anacrotic-type tracing.

Together with PERNOD, we studied the carotid cardiogram of 1000 patients in function of age group (each group covering a ten year span). This anacrotic type is unusual in the 18 to 29 year age group, occurring in only 0.34 %.

This type rises slightly in the 30 to 39 year age group (2.80 % ) but in the 40 to 50 year age group there are 14.25%. Hence 15% of the pilots aged 40 years present anacrotic type tracing which reflects changes in the elasticity of the arterial wall.

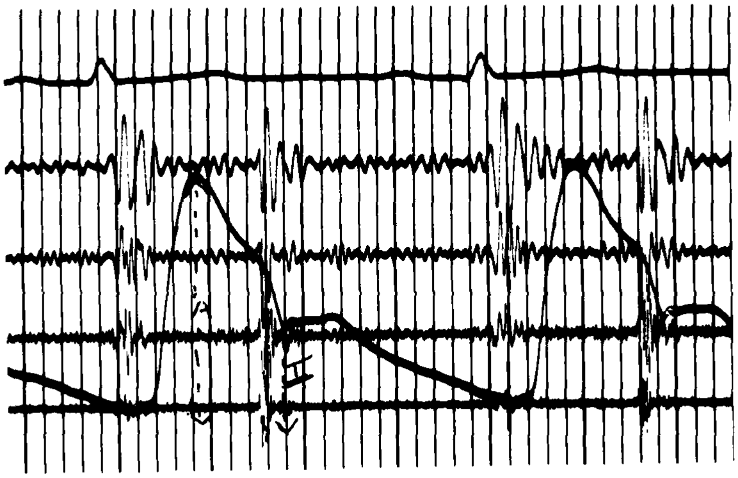


Figure 8

I/A ratio of a normal carotid cardiogram

b) Investigation of the I/A ratio

Other changes also occur with age, including the ratio of the height of the notch (I) over the amplitude of the pulse wave (A) which is increased. With NOGUES we determined this I/A ratio in 250 pilots. In three age groups the ratio was found to rise with age.

Group one: number of subjects : 100 (age 17 to 29 years) - Mean age : 21 years

$\frac{I}{A}$ = m 21 $\pm$ 2 m 21 = 0.437 $\pm$ 0.020

Group two: number of subjects : 70 (age 30 to 52 years) - Mean age: 41 years

$\frac{I}{A}$ = m 41 $\pm$ 2 m 41 = 0.569 $\pm$ 0.023

Group three: number of subjects : 80 (age 32 to 78 years) - Mean age : 53 years

$\frac{I}{A}$ = m 53 $\pm$ 2 m 53 = 0.586 $\pm$ 0.020

By means of a study involving a hydraulic model NOGUES was able to show that the $\frac{I}{A}$ ratio of the carotid cardiogram (i.e. the ratio of the height of the catacrotic notch over the amplitude of the pulse wave) reflects the elasticity of the arteries.

In practice, this ratio increases when the elasticity of the hydraulic system falls or when the peripheral resistances rise; for a given diastolic pressure, the $\frac{I}{A}$ ratio increases if the elasticity of the walls of the model are reduced or if the resistance during each action increases. The loss of arterial elasticity therefore appears to be linked with one of the following:

- either a degenerative parietal factor specific to the segment tested,
- or to a peripheral factor, obstructing the flow of the liquid.

In this model, the amplitude of the dicrotic wave would appear to be reduced the lower the arterial elasticity.

This once more draws attention to the usefulness of investigation of the $\frac{I}{A}$ ratio of the carotid cardiogram which provides a rapid method of assessing the elasticity of the arterial system.

## IV - CHRONOCARDIOGRAPHIC STUDIES

Since the intervals of the chronocardiogram depend on the extent of myocardial damage, it is logical to investigate the possibility of correlation between the various intervals and the haemodynamic data provided by cardiac catheterisation and ventricular angiography. This was carried out by:

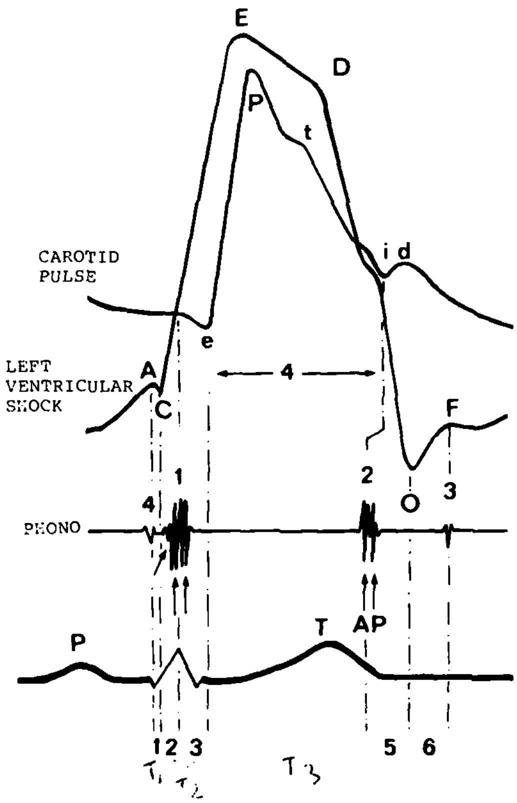
WEISSLER (1970) and ARONOW (1971) in the investigation of the contraction of myocardial muscle.

But before considering their work, we should recall the various determinations carried out during chronocardiography .

T.1: electromechanical interval from point Q on the electrocardiogram to point C on the apex cardiogram.

T.2: or the preexpulsive interval extending from point C on the apex cardiogram to point E on the carotid pulse. This preexpulsive interval can be divided into two parts: T2A or the preisometric contraction from point C of the apex cardiogram to the closing of the mitral valve i.e. to the first high speed component of S1 and PQS on the phonocardiogram or the isometric contraction of mitral closing or point E on the carotid pulse.

T.3: or the systolic ejection time from point E to the catacrotic notch of the carotid pulse cardiogram but these determinations must be corrected to allow for the heart rate.




T3 varies inversely with the heart rate. Using WEISSLER's regression equations we can calculate the following:

$$T.3^{c} = T.3 + 1.7 \text{ R.R.}$$

In this equation, the normal T.3 is 413 $\pm$ 10 ms (normal extrapolated value for zero heart rate). Using the PERNOD and CARRE grid, which is based on the linear relationship between T.3. and R.4. we obtained the following:

$$T.3^{c} = 1.02 \text{ T.3.} + 195.4$$

However, when investigating the relationship between HR and T.3 in a large number of healthy subjects, COLIN and CARRE regularly detected a linear correlation different from that obtained by WEISSLER. In 1978, they sugested the following correction formula:

$$T.3^{c} = T + 1.4 \text{ R.R.}$$

The normal range for $T.3^{c}$ is 3 x T.3 $\pm$ 13.3 ms.

These three time intervals determined using classical external mechanography have been confirmed by comparison with invasive methods. Studies carried out by numerous authors have provided similar results.

T.3 external and T.3 invasive have been studied in particular by BORSH, MARTIN, VAN DER VERF. The T.3 determined from the carotid cardiogram was compared with the simultaneous recording of the blood pressure at the base of the descending aorta by a catheterisation method. The coefficients of correlation ranged from 0.97 to 0.99 depending on the author, the invasive T.3 was generally 3 to 4.5 ms shorter than the non-invasive T.3.

The validity of determination of the total electromechanic systole from the interval T.1 + T.2 + T.3 has been established by ANASTASSIDES and BROUGH ( experiment in the dog, correlation of coefficient 2 = 0.90).

The validity of the determination of T.2 by an external method has also been established by comparison with an invasive determination by BUSH and METZGER who obtained correlation coefficients of 0.94 to 9.98. The value of determining these systolic time intervals has been demonstrated.

METZGER has shown that the preejection period is closely related to the isovolumetric contraction time, the electromechanical interval being relatively constant between 30 and 40 ms. AHMED has also shown that there is good correlation between the value of T.2 and the maximum speed of pressure change in the left ventricle. The T.2/T.3 ratio is very important in evaluation of the myocardial contractility. According to WEISSLER, this is closely correlated with the cardiac index. It is also more sensitive than this index and may detect abnormalities before these are apparent from the cardiac index (LEWIS).

GARRAND has shown that the T.2/T.3 index also shows excellent correlation (2 = 0.90) with the angiographic ejection fraction. Determination of the systolic time intervals applied and analysed in this way provides a sensitive clinical evaluation of the degree of deterioration of the performance of the left ventricle. This method is easily reproducible and quantitative.

This method has been used in aeronautical medicine, STAFFORT used it to investigate circulation changes induced by changes in body position. GRAYBOYS used the method to investigate cardiovascular response to the lower body negative pressure test and to accelerations + G 2 (the heart rate, T.3, 5.2 and T.2/T.3 ratio increase in proportion to the level of acceleration and return to normal values after 60 s of rest). With FITCUSSI the authors used this method during physical exercise and have shown the value of the T.2/T.3 ratio in assessment of physical fitness from a cardiovascular point of view. But this well documented method does have some drawbacks. The carotid sensor is difficult to fit and only the left heart is investigated. For this reason COLIN, after correlation with cardiac mechanograms, suggests that the systolic time intervals be determined by means of cardiac plethysmography involving electrical impedance. This elegant, simple and non-invasive method is being checked and will probably be of great value in aeronautical and space medicine.

# CHAPTER 7

## ECHOCARDIOGRAPHY IN THE EXPERT EXAMINATION OF FLYING PERSONNEL

by J. Droniou* and A. Coignard**

Internal cardiac structures can be visualised by means of echocardiography because an ultra-sonic beam can be reflected by these structures. This method was introduced into clinical practice in the 1950's and developed with extraordinary rapidity to become an essential examination in Cardiology.

It is non-invasive and relatively simple and so can be repeated as often as required. The method is also highly sensitive and reliable when used by experienced personnel and so merits an important place in the expert cardiological examination of flying personnel.

### 1. GENERAL REMARKS

### I.1 The principle of echocardiography

Ultra-sound (US) is an oscillation inaudible to the human ear because of its high frequency (20,000 to 10 million cycles per second, i.e. 20,000 Hertz to 10 Mega-Hertz). The propagation of a US beam depends on the acoustic properties (acoustic impedance) of the media through which it passes. If the beam encounters media of differing acoustic impedance, its path undergoes reflection and refraction phenomena.

One fraction of the beam is refracted, i.e. continues its path following deviation. The other fraction is reflected and this gives rise to an echo at the interface.

This property is the basis of echocardiography which sets out to capture the beams reflected by the cardiac structures and to visualise the corresponding echos. This is possible because ultra-sound is well propagated in the soft tissue of the human body just as in water.

### I.2 Transducers

The ultra-sound (US) source or transducer also acts as a receptor. It consists of a piézo-electric quartz slide which, under the action of a high frequency electrical wave generator vibrates at the same frequency as the changes in potential. Emission is discontinuous consisting of short bursts of waves. Between two successive emissions the system acts as a receptor: the quartz transforms the vibratory energy of the reflected beam into electrical potential variations of the same frequency.

The impulse frequency determines the number of images of the cardiac structures received per second: 1,000 in one-dimensional ultra-sound, 30 to 60 in two-dimensional ultra-sound.

The US radiation frequencies used in cardiology are of the order of 2.2 to 3.5 Mega-Hertz in adults and 5 to 7 Mega-Hertz in children.

### I.3 Visualisation of reflected echos

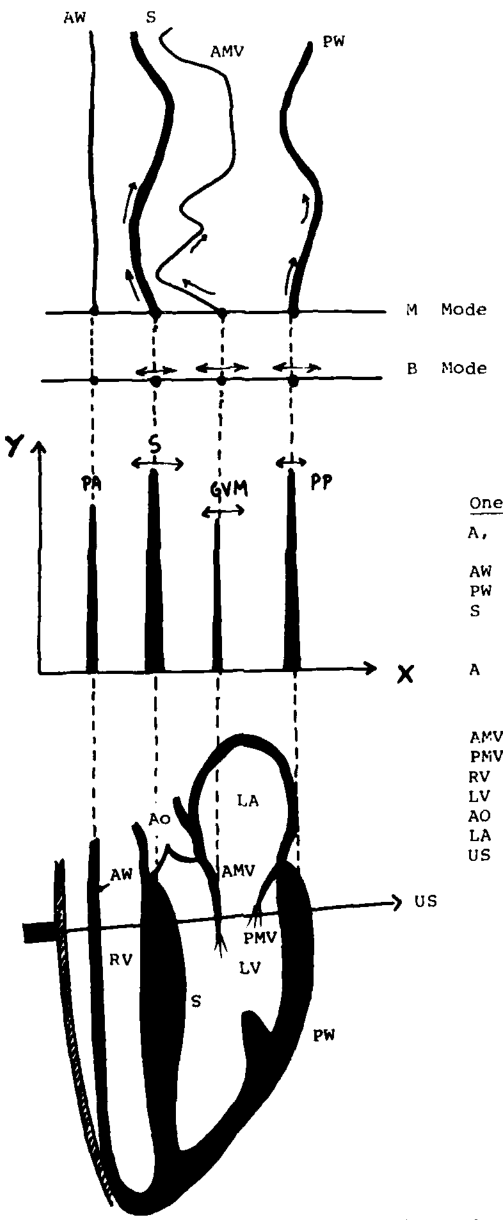
After transformation of the acoustic signal into an electrical signal, the electrical signal is amplified and then recorded by a suitable instrument: oscilloscope; television screen equipped with memory, fiberoptic recorder. There are several types of echocardiography depending on the type of transducer used and the method of visualising echos.

* Médecin en Chef, Chef du Service de Cardiologie de l'Hôpital d'Instruction des Armées du Val-de-Grâce.

** Médecin en Chef, Médecin Adjoint du Service de Cardiologie de l'Hôpital d'Instruction des Armées du Val-de-Grâce.
74 Boulevard de Port-Royal,
75230 PARIS CEDEX 05
FRANCE.

## I.4 One-dimensional echocardiography

This involves a single transducer emitting one US beam. The echos can be represented in three ways (See Figure 1)




One Dimensional Echography

A, B and M modes:

AW - anterior wall
PW - posterior wall
S - septum

A Mode

AMV - anterior mitral valve
PMV - posterior mitral valve
RV - right ventricle
LV - left ventricle
AO - aorta
LA - left atrium
US - direction of the beam

Figure 1

I.4.a A Mode (amplitude modulation ultra sound)

The Echo reflected from an interface is displayed on the oscilloscope as a bright pip the amplitude of which is proportional to the energy of the reflected beam. Its position on the X-axis depends on the distance of the interface from the transducer.

Ultra-sound travels at a constant speed of 1500 metres per second through the soft tissues of the human body and so the X-axis can be calibrated by measuring the time taken by the ultra-sound beam for the return journey between the transducer and the echos.

In this mode of echocardiography, cardiac structures are in practice defined only by their relative positions on the X-axis.

I.4.b B Mode (brightness-modulation ultra-sound)

The reflected signal is displayed as a bright dot, the brightness of which is proportional to the intensity of the reflected signal.

I.4.c M Mode (Time-motion ultra sound)

The echo is recorded in the B mode presentation. Cyclic approach and withdrawal of the echos from the probe during the heart cycle are visualised in function of time by means of a constant speed chart recorder. Synchronised recording of the electrocardiogram, the phonocardiogram or an external mechanogram provides time scale references.

Time-motion ultra sound is widely used. Cardiac structures are identified both from their distance from the transducer and the characteristic curve produced by their motion in function of time. The good definition of time-motion electrocardiograms makes possible highly accurate quantitative investigation of the amplitude and speed of movement of cardiac structures.

The main drawback of the time-motion mode results from the fact that the heart is visualised only in a very limited zone along the access of the single exploratory beam. Exploration of neighbouring zones require the gradual shift of the angle of the transducer in the method known as the compound scan. It is therefore difficult to determine the spatial arrangement and relationships between the various cardiac structures.

## I.5 Two-dimensional Echocardiography

This method provides dynamic echotomographic sections through the heart. Various technical approaches have been suggested. We will outline the principles behind the two major methods, which provide extremely rapid reconstitution of sections of the heart in motion, virtually in real time (see figure 2).

### I.5.a - Multiscan technique

This method was developed following the work of Bom and uses an array of 20-60 transducers placed side by side. One after the other the transducers emit discontinuously. The corresponding echos are presented in the B mode before the emission of the following transducer. If the emission frequency is sufficiently high (20 to 60 impulses per second) tomographic sections are obtained virtually in real time. The records obtained using this technique are of fairly poor quality in the adult.

### I.5.b - Sectorscan technique

This method involves one or more transducer(s) carrying out angle-sweeping movements between 60 and 90° with a scan frequency of 30 to 60 cycles per second. The scan may be regulated by mechanical or electronic means. Thus the B Mode presentation provides visualisation of triangular sections through the heart virtually in real time. Image definition is excellent but however, less good than using the time-motion method particularly with respect to the endocardium which is less well imaged.

Real Time Echocardiography
1. Multiscan
2. Sectorscan
(After LESBRE)

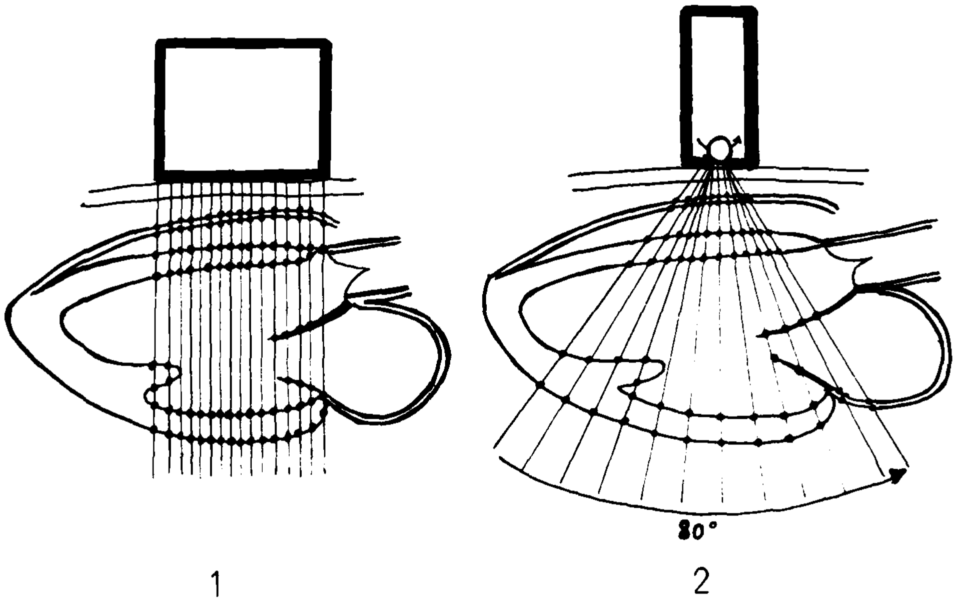



Figure 2

## I.6 Other electrocardiographic methods

### I.6.a Contrast echocardiography

Blood, which is a homogeneous medium from the purely acoustic point of view, does not reflect ultra-sound. Rapid injection of a liquid bolus (physiological serum) into a peripheral vein results in the formation of microspheres within the liquid flow. These microspheres are preserved into the right cavities of the heart. By changing the homogeneous acoustic nature of the small volume of blood containing them,they produce echos which can be detected by time-motion or two-dimensional ultra-sound. We will not discuss this method any further which is used essentially in cases of right, left shunts or tricuspid incompetence.

### I.6.b Pulsed Doppler echocardiography

This method has recently been introduced into clinical practice and makes possible the simultaneous recording of the time-motion electrocardiogram and the characteristic curves of the blood flow analysed by the Doppler effect at an exact site within the cardiac cavities using a single transducer. The position of a small volume of blood analysed (2 x 5 mm) is detected on the electrocardiogram by a marker (the Doppler window) . The exploration is guided by means of Doppler sound recording.

The pulsed Doppler method provides qualitative analysis of pathological or physiological intra-cardiac blood flow. Attempts to determine the speed have met with a major obstacle: the absence of information concerning the angle made by the ultra-sound beam with the direction of the blood flow, this information is essential to the calculation of the speed.

I.6.c Micro-computer electrocardiographic link-up

Electrocardiography can determine some data concerning left ventricular function. For some of these indices manual deciphering of the recordings is lengthy and this restricts their use. This consideration has led to the routine use of micro-computers. The echographic recording is placed on a numerical graphic table. As the operator moves a sensitive pencil along the echos under analysis, the corresponding graphs are converted into numerical form and simultaneously processed by the computer. Results are provided in the form of numerical and graphical data. Some echocardiographic systems are marketed with a micro-computer built in. Rather than such an assembly which is convenient but restricted and expensive, an independent and adjustable system may be preferred which can be adapted to the input and processing of highly varied signals.

I.7 Limitations and general perspectives

I.7.a General Limitations

These result mainly from the restriction of ultra-sound propagation in the tissues of the thoracic wall. Some subjects have narrow intercostal spaces which hinder this examination (since the ultra-sound is reflected by the bony structures) This method of exploration is difficult in patients with emphysema because of the presence of air, which has low ultra-sound permeability, between the wall and the heart. The method is also difficult to use in elderly, obese or highly muscular subjects.

This means that the examination may sometimes be lengthy and may provide an echocardiogram of poor quality which increases the risk of errors of interpretation and which is unusable for accurate determinations.

I.7.b Perspectives

Despite this, the ultra-sound method is advancing at a spectacular rate. The definition of real time images should continue to be improved over the coming years. Pulsed Doppler echocardiography is beginning to be coupled with real time ultra-sound and this makes it possible to determine the volume of blood under study more accurately. The use of Doppler systems with multiple windows, and visualisation in the form of colour scales of the blood flow obtained are improvements which can be expected in the near future. Computerised three-dimensional echocardiography is currently under study.

II / THE NORMAL ECHOCARDIOGRAM /

Whatever mode of echocardiography is used the patient is examined in the dorsal decubitus or slightly left lateral decubitus position. The transducer is applied using an air-impermeable conducting paste:

- either on the internal part of the 3rd or 4th left intercostal space (standard parasternal incidence)

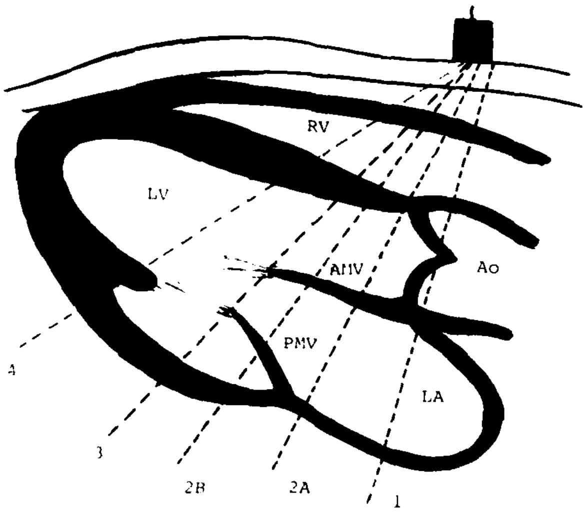
- or in the sub-xyphoidal region (the suprasternal or sub-clavicular fossa) at the apex tap.

II.1 T.M. Echocardiography (TME)

The standard parasternal incidence is usually adopted, the others being used either because it has failed or in order to give preferential visualisation of certain structures. They may also be used in the case of pulsed Doppler in order to have an ultra-sound beam roughly parallel to the direction of the blood flow under study.

In the standard parasternal incidence, the transducer explores the heart through a narrow window delimited by the sternum and the ribs above and below. The cardiac structures are visualised at an angle similar to left anterior oblique (LAO) of angiocardiography (See figure 3).

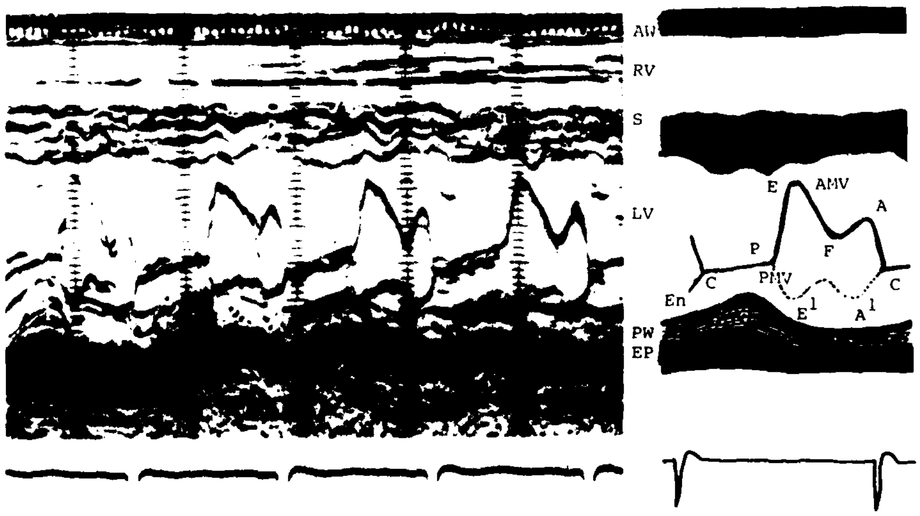
There is a standard method of examination: after visualisation of the echo characterising the mitral valves, small shifts in the angle of the detector are used to select other incidences. The examination must include an aorta-apex scan and a return scan during which the angle of the recorder is gradually shifted without changing intercostal space, in order to visualise the usual positions successively (1-2-3-4).




II.1.a Trans-Mitral incidence

This incidence provides visualisation of the anterior mitral valve (2A, figure 3) or of both flaps of the mitral valve (2B, figure 3) which undergo a highly characteristic movement (figure 4)

Figure 4



During systole, the echos from both valves are applied one over the other to produce a single horizontal or slightly rising line CD. During diastole, the valves move in the other direction, to produce a mirror image: the anterior flap (AMV) moving forwards towards the septum, and the posterior flap (PMV) backwards towards the posterior wall. During this diastolic pathway the AMV traces an M-shaped movement, and the posterior flap a W-shaped movement to return and meet again at point C where the mitral valve closes. In the normal subject, point C is nearer to the posterior wall than to the septum. The movement of the PMV is equivalent to about one-third that of the AMV.

Table 1 provides an indication of the normal ranges of values in the adult and of the significance of parameters measured in this incidence.

TABLE 1

NOMENCLATURE AND SIGNIFICANCE OF CHANGED MOVEMENT OF THE AMV

| NOMENCLATURE | SIGNIFICANCE | FACTORS INVOLVED | NORMAL RANGE OF MEAN VALUES |
|---|---|---|---|
| CD | Systolic closing of the flaps | Anterior shift of the mitral ring | - |
| DE | Amplitude of maximum opening of the AMV | - elasticity of the valve<br>- atrioventricular gradient and trans-mitral flow | 20-33 mm |
| EF Slope | Mean rate of proto diastolic closing of the AMV (rapid filling of the LV) | - elasticity of the valve<br>- AV gradient and transmitral flow<br>- LV compliance | 75-150 mm/sec. |
| FA | Slow filling of the LV | - | - |
| A | Presystolic reopening of the AMV | - atrial contraction<br>- elasticity of the valve | - |
| AC Slope | Rate of closing | telediastolic LV pressure | 125-250 mm/sec. |

II.1.b Aorta-left atrium incidence

This incidence (1°figure 3) visualises from above downwards, i.e. from the front to the back relative to the transducer, the pulmonary infundibulum, the root of the aorta with the antero-right and posterior semilunar valves, and the left atrium (figure 5).

Echos from the anterior and posterior walls of the aorta undergo parallel displacement, forwards during systole and backwards during diastole. The semilunars, are closed during diastole and the echo is narrow, more or less median and parallel to the aortic walls. During systole, the valve flaps are laid back against their respective aortic walls. They open and close suddenly (rectangular-shaped "boxed").

This incidence provides a reliable determination of the transverse diameter of the infundibulum, of the aortic ring and of the left atrium (LA), carried out during telesystole. The determination of the semilunar opening is less reliable since it depends on the angle of incidence of the US beam. Table II summarises the main parameters determined in this incidence and the range of normal values in the adult.

Figure 5

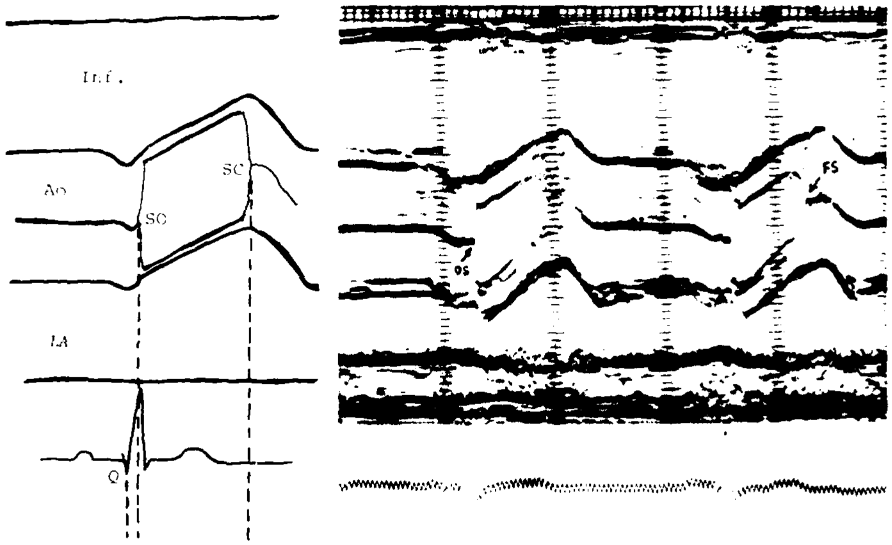


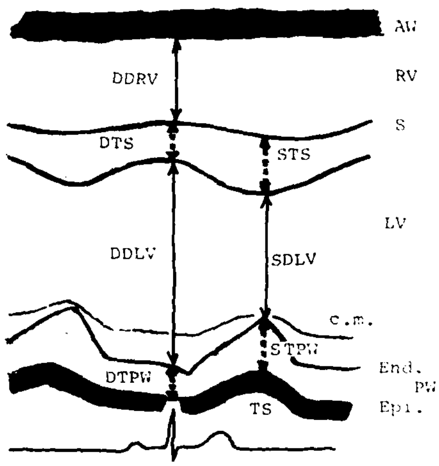

TABLE II PARAMETERS DETERMINED IN THE AORTA-LA INCIDENCE

| PARAMETER | Determination | Normal value |
|---|---|---|
| Internal diameter of the aortic ring | distance between the two walls during telesystole | 20-37 mm |
| Thickness of the aortic walls | - | ≤5 mm |
| Distance travelled by the aortic walls | distance between the tele-systolic advance and tele-diastolic withdrawal of the wall | 7-10 mm |
| Semilunar opening | during protosystole | 16-26 mm |
| Transverse LA diameter | distance between the post-aortic wall and the posterior wall of the heart during telesystole | 19-40 mm |
| Diameter of the pulmonary infundibulum | during systole | 20-35 mm |
| LV ejection time | from SO to SC | Ejection time corrected as a percentage of the normal (100%) (Meyners Tables) |
| Pre-ejection period | Time between the ECG Q-wave and SO | 0.04 ± 0.02 sec. (Heart rate 70/mn) |

II.1.c Sub-mitral incidence

From the mitral incidence, the transducer is turned slightly towards the apex so that only part of the rapid opening of the AMV remains within the path of the beam (incidence 3 figure 3). The right ventricular cavity(RV) and the left ventricular cavity (LV) which are separated by the septum are visualised from front to back (figure 6). The septum and the posterior wall of the LV approach one another during systole and move apart during diastole.

Figure 6




This incidence can be used to determine the transverse diameter of the left ventricle during telediastole (DTLV) and during telesystole (STLV) between the left edge of the septum and the posterior endocardium. The telediastolic diameter of the RV (DTRV), the telediastolic and telesystolic thicknesses of the septum (DTS, STS) and of the posterior wall (DTPW, STPW) are also determined. Figure 6 shows the way in which these various parameters are determined and the normal ranges of values are shown in Table III.

TABLE III PARAMETERS DETERMINED IN THE SUB-MITRAL INCIDENCE

| PARAMETER | Normal range of values in the adult |
|---|---|
| Telediastolic diameter of the LV (DDLV) | 37-56 mm |
| Telesystolic diameter of the LV (SDLV) | 25-40 mm |
| Telediastolic thickness of the septum (DTS) and of the posterior wall (DTPW) | 6-11 mm |
| DTS/DTPW ratio | $\leq$ 1.3 |
| Telediastolic diameter of the RV (DDRV)<br>in dorsal decubitus<br>in lateral decubitus | 30 mm<br>7-23 mm<br>9-26 mm |
| Systolic path S<br>PW | 4-8 mm<br>9-14 mm |

II.1.d Other incidences

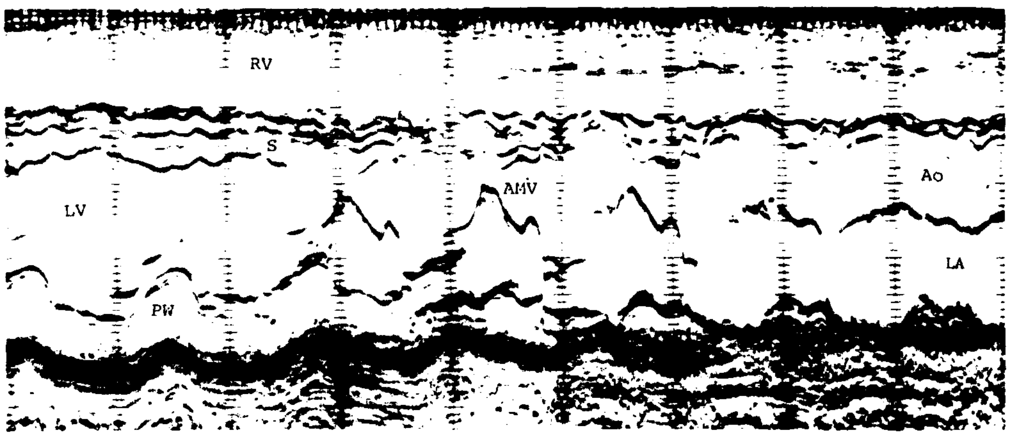
- Tricuspid: the movement of the anterior and septal leaflets has the same form as that of the mitral valves. However, in the normal adult, usually only part of the systolic movement and the protodiastolic opening of the anterior valve is visualised (gull wing shape).

- Pulmonary orifice: the pulmonary valves are easily detected in the child. In the adult, the posterior semilunar may sometimes be visualised usually only during its diastolic path.

II.1.e Aorta-apex scan (figure 7)

This checks the continuity of the septum with the anterior wall of the aorta, of the AMV with the posterior wall of the aorta, and of the posterior wall of the LV with that of the LA. The upper part of the septum moves in unison with the aortic wall (forwards during systole).

Figure 7




II.2 Two-dimensional Echocardiography (2DE)

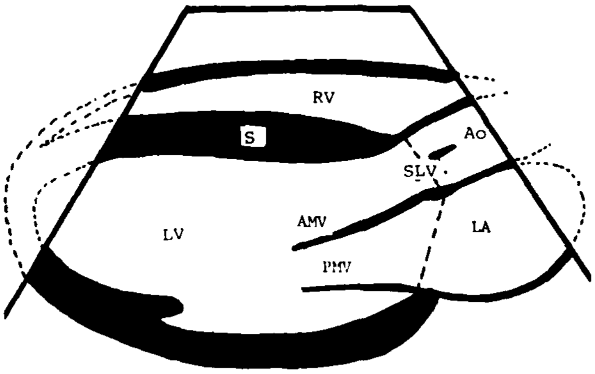
This can provide a variety of echotomographic sections through the heart some of which standardised.

II.2.a Standard parasternal incidence

Two section planes are possible:

a) sagittal section through the main axis: figure 8 shows the cardiac structures visualised overall and in real time in this incidence. Using a 90° sector scanner, only the very tip is missing from the overall visualisation. The semilunar valves, laid flat against the aortic walls during systole are visible during diastole (narrow median echo). The mitral and aortic rings are at an angle of 95 to 110° open towards the apex. The area of systolic meeting of the mitral leaflets is at the junction between the posterior third and median third of the posterior-wall septum line. The angular movement of both valves can be studied, the leaflets never go further than the plane of the mitral ring.

- FIGURES 8 A - 8 B -

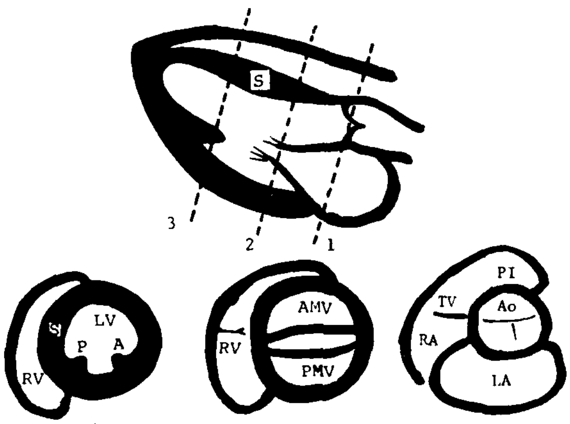



8A

8B

b) transverse sections through the short axis : these may be carried out at three levels (figure 9). The section through the large vessels provides information concerning semilunar opening. The section through the mitral system shows the concentric contraction of the LV and allows calculation of the area of the mitral orifice. *The third section is through the mitral pillars.*

- FIGURES 9A - 9B -




9A

9B

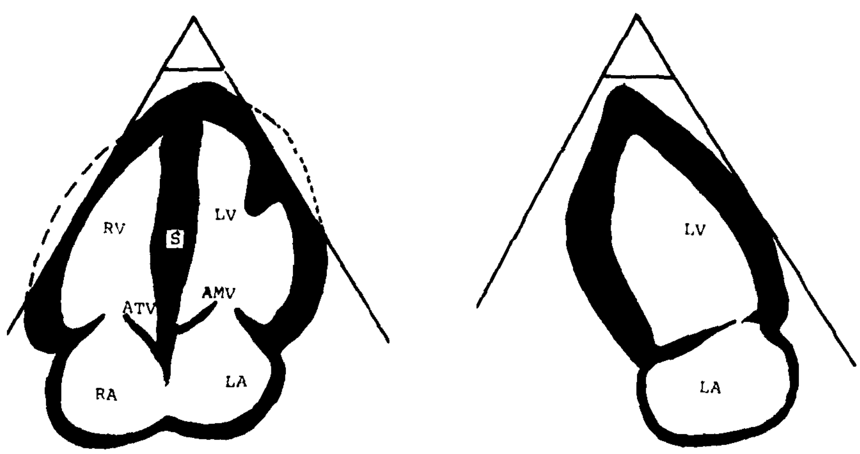
II.2.b Apical incidence

The transducer is placed on the apex tap with the subject in the left lateral decubitus position and the ultra-sound beam is directed towards the atria.

a) the four cavity section (figure 10 A) is perpendicular to the septum. The septum is clearly distinguished as are the mitral and tricuspid valves, and the ventricular and atrial cavities. In this section, the lateral wall of the LV can be investigated .

b) The LV-LA section (figure 10 B) is obtained by turning the transducer until the RV disappears. This gives good visualisation of the anterior and posterior walls of the LV, of the mitral system and the LA.

Figures 10A and 10B




10 A    10 B

II.3 Pulsed Doppler echocardiography (PDE)

An example of a normal recording is shown in figure 11A: the Doppler window is behind the anterior tricuspid valve. The normal diastolic transtricuspid flow is visualised and is seen to be free from turbulence. The absence of any systolic flow is confirmed. This picture should be compared with that of figure 11B with the Doppler window in the same position . Fig.11B shows tricuspid incompetence taking the form of holosystolic flow turbulence in the right atrium.

III / ECHOCARDIOGRAPHY IN HEART DISEASE /

Echocardiography can be used both to identify anatomical lesions, sometimes with the mechanism involved, and also to assess their haemodynamic effects and the functional condition of the myocardium.

III.1 Haemodynamic effects and myocardial function

Figure 11A

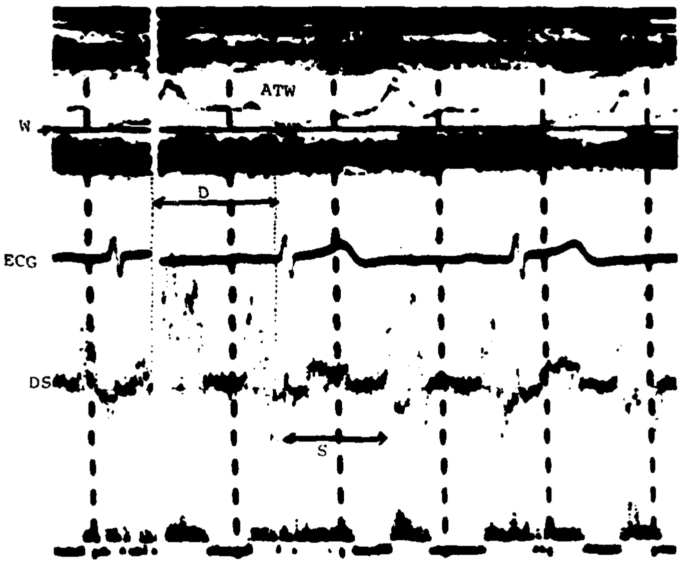



Figure 11B

III.1.a Haemodynamic effects of pathological heart conditions

The characteristic echocardiographic signs are present only in advanced and/or established heart disease. Despite this lack of specificity, especially

during the decompensation phase, they can give some indication of the type of heart disease involved.

TM Echocardiography:

This method provides an accurate assessment of the dilatations of the LV and LA cavities and (often with less success) of the RV. The method also determines the thickness of the walls and their kinetics. In this way various electrocardiographic syndromes have been described which correspond to severe but still compensated heart diseases.

VOLUME OVERLOADING OF THE LV (figure 12) is reflected in an increase in the telediastolic diameter and in hyperkinesis of the walls, detected from the length of the pathway of the septum and of the posterior wall. The consequence of such overloading is increased ejection indices (see below).

Figure 12


PRESSURE OVERLOADING of the LV (figure 13) involves hypertrophy of the walls with a small cavity (reduced or normal DDVL). The concentric nature of the hypertrophy is shown by a symmetrical increase in the diastolic thicknesses of the septum and of the posterior wall, the DTS/DTPW ratio remaining below 1.3. The EF slope of the AMV, is often reduced, reflecting hampered filling of the LV, the elasticity (compliance) of which is reduced.

VOLUME OVERLOADING OF RV results in an increase in the TDDRV, and a paradoxical movement of the septum which, during systole, moves forward in the same direction as the posterior wall (figure 14). Similar abnormalities in the movement of the septum may be detected during complete left bundle branch blocks and in type B WPW syndromes. In the dilated RV, the tricuspid valve is often visualised with abnormal ease and completeness.

Pressure overloading of the RV is much less clearly characterised.

DURING THE DECOMPENSATION STAGE of heart disease affecting the left ventricle, the left cavities are dilated and the walls hyperkinetic (hence a marked reduction in the efficiency index). There are associated abnormalities of the movement of echos from the mitral and semilunar valves related to the fall in heart output and the increased telediastolic pressure of the LV (figure 15). These signs, which reflect very serious heart disease, are of little interest in the expert examination of FP.

2D Echocardiography

This technique complements that of TME and provides global visualisation of the dilatations of the cavities and real time kinetics of the walls. This method is les suitable for quantitative studies but particularly valuable for determining the following:

- dilatation of the RV and especially of the RA (the latter being inaccessible to TME)

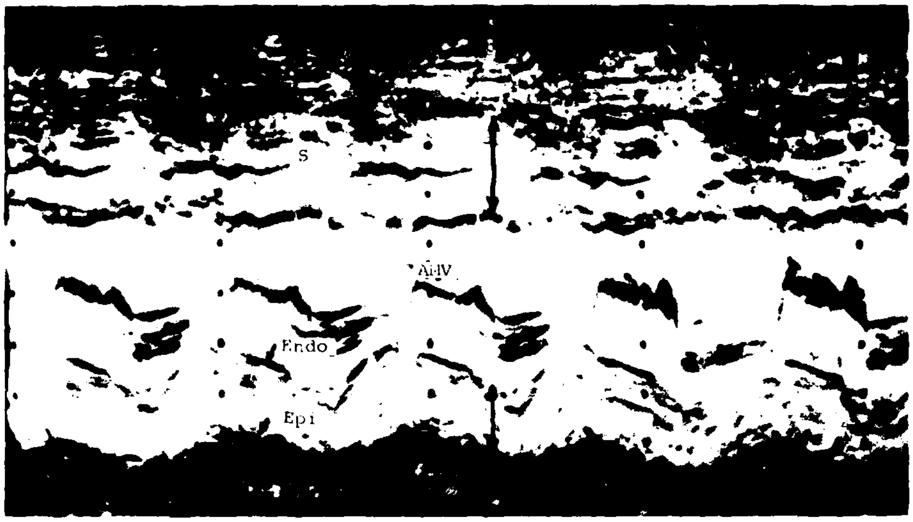
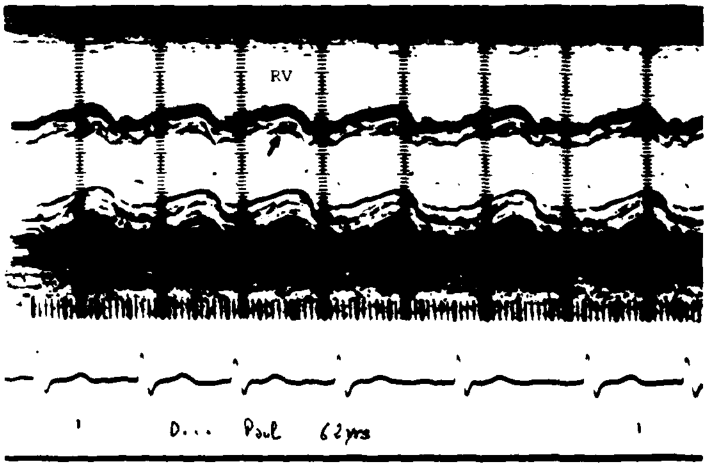


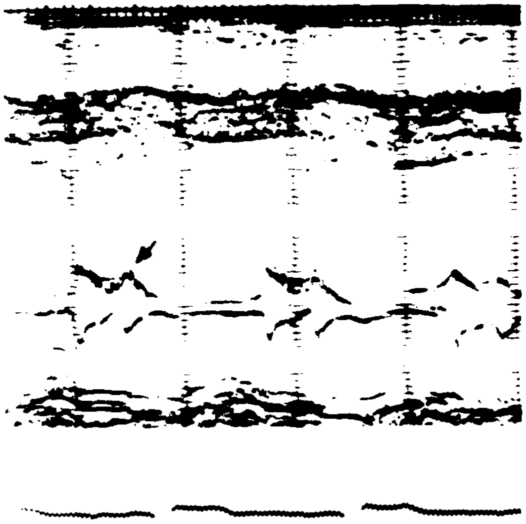

Figure 13

Figure 14




- segmental abnormalities in the left ventricular contraction characteristic of some heart disease conditions.

Figure 15



III. 1.b Left ventricular function

Echocardiography can determine the left ventricular efficiency index which may be effected before any clinical signs of heart disease are apparent; this is of great value in the expert examination of FP.

TM Echocardiography

The left aorta-atrial incidence (figure 5) with simultaneous ECG recording allows calculation of the systolic times to be made as from external phonomechanograms.

The sub-mitral incidence is used to determine a series of indices which establish the systolic ejection function of the LV and the diastolic filling function.

1) Systolic function of the LV (Table IV)

| EFFICIENCY INDEX | | CALCULATION | NORMAL VALUE |
|---|---|---|---|
| OVERALL | Ejection index | $\frac{DD - SD \times 100}{DD}$ | 30-40 % of DD |
| | Ejection fraction | $\frac{DD^3 - SD^3}{DD^3} \times 100$ | 60-75 % of the diastolic volume |
| | Mean VCF | $\frac{DD - SD}{TT \times DD}$ | 1-1.9 DD per sec. |
| | Max VCF | $\frac{dD/dt \ Max}{D}$ | 1.5-3 D per sec. |
| LOCAL | Thickening fraction | $\frac{ST - DT \times 100}{DS}$ | S 15%-60% ($\overline{45}$%)<br>PW15%-80% ($\overline{65}$%) |
| | Mean thickening rate | $\frac{ST - DT}{DT \times TT}$ | S $\overline{1.70}$ DT per sec.<br>PW$\overline{1.9}$ DT per sec. |
| | Max. thickening rate | $\frac{dT/dt \ Max}{T}$ | S $\overline{3.9}$ T per sec.<br>PW $\overline{4}$ T per sec. |

The global indices of systolic function are calculated from changes in the transverse diameter of the LV during systole. Three indices should be noted :

- the *EJECTION INDEX corresponds to the reduction of the diameter during* systole (DDLV minus SDLV). In order to take account of individual variations in LV size, this is normally expressed as a percentage of the telediastolic diameter. Like the ejection fraction, this parameter assesses LV pump function.

- the MEAN RATE OF DIAMETER SHORTENING is the systolic shortening of the diameter divided by the ejection time. Expressed in terms of diastolic diameters per second this is equivalent to the normalised mean rate of shortening of the circumferential fibres of the myocardium evaluated using an angiocardiograph and expressed in terms of circumferences per second (VCF mean). The VCF is considered to be a good index of contractility.

- MAXIMUM RATE OF SHORTENING OF THE DIAMETER (VCF max.) This is more sensitive than the mean VCF but its determination requires a micro-computer to calculate the peak of the derivative of the diameter in function of time (dD/dt Max ). It is expressed in normalised form as instantaneous diameter.

- the EJECTION FRACTION can be assessed using the electrocardiograph if some hypothetical geometric shape is assigned to the LV. If this is considered as a turning ellipsoid the long axis of which is double the small axis which is equal to the transverse echographic diameter, the volume of the LV is virtually equal to the curve of this diameter. The systolic volume can therefore be calculated ($SEV = DD^3 - SV^3$) as can the ejection fraction ($EF = \frac{DD^3 - SD^3}{DD^3}$) .

From investigation of variations in the thickness of the septum (DTS and STS) and of the posterior wall (DTPW, STPW) it is possible to assess the contractility of the two walls from the following:

- SYSTOLIC THICKENING OF THE SEPTUM AND OF THE POSTERIOR WALL, expressed as a percentage of diastolic thickness ( thickening index).

- MEAN RATE OF SYSTOLIC THICKENING, expressed as diastolic thicknesses per second.

- MAXIMUM THICKENING RATE, which requires a computer.

ii) diastolic function of the LV

Hindrance of LV filling is an important haemodynamic factor in hypertrophic or restrictive myocardiopathy.

*Overall diastolic function is assessed from the mean rate of protodiastolic* closure of the AMV (EF slope). But this index has low sensitivity and is non specific, being influenced particularly by organic changes of the valve. This led GIBSON to suggest two more sensitive and reliable indices which require computer calculation: the duration of the rapid filling phase and the maximum rapid filling rate (peak of the derivative of the diameter in function of time).

iii) the value of LV function indices determined from TME

The indices evaluated directly from diameters are reliable for regularly contracting ventricles (normal subjects, valvular conditions, non-coronary artery hypertension). A standardised test is required involving 2DE in particular, to ensure that the transverse diameter is measured and not an oblique diameter. The ejection index is closely correlated with the ejection fraction determined by angiocardiography and the VCF is at least as reliable as that determined by angiocardiography.

Determination of volumes from these diameters is only a rough approximation, since the hypothetical geometric shapes assigned to the LV are not confirmed for pathological LV. Regression formulae have been suggested to overcome this drawback. **The authors believe that only indices derived directly from the diameter should be used in practice.**

**The overall assessment of myocardial function from the diameter determined in a very limited region of the LV, situated in the axis of the ultra-sound beam, is subject to both over-and under-estimation if there are any segmental abnormalities of contraction as is the case in ischaemic heart diseases and many hypertrophic cardiomyopathies. In such cases, the local contractility indices retain their value especially when determined with the aid of a 2DE.**

- 2D Echocardiography

This method can be used to determine the ventricular volumes and the ejection section by methods similar to those used in bi-planar angiocardiography. The volume determinations obtained correlate well with those obtained by angiocardiography even in patients with ischaemic heart disease. However it should be remembered that the number of echographic images of the walls obtained per second (30 to 60) is much smaller than that obtained by TME (1,000), that the endocardium is much less well distinguished than by TM and also that analysis of the apical region is difficult. These restrictions make the method tricky to use and demand highly experienced technicians. The complexity of the measurements and calculations requires the use of a computer. For these various reasons, the method is not yet in routine use.

In practice, combination of 2DE and TME provides a simple, rapid and reliable means of assessing LV function. The 2DE is used to detect any segmental abnormalities of contraction and to direct investigation of the transverse diameter so confirming determinations obtained by TME.

III.2 Diagnosis of heart disease

We will limit ourselves to conditions likely to be encountered during the expert examination of FP.

III.2.a Cardiac valve disease

a) Mitral stenosis (MS)

This condition rules out any aeronautical activity and we will not consider it in any detail even though the diagnosis and assessment of the severity of this condition are amongst the major contributions of echocardiography. However the clinical signs, which are usually evident, and its rapid haemodynamic effects result in the fact that this condition is very rarely discovered in a truly "silent" state during paroxysmal tachyarrhythmia or a thromboembolic incident.

TME suffices to establish the diagnosis which can be obtained in 100% of cases from association of 2 essential signs (figure 16).

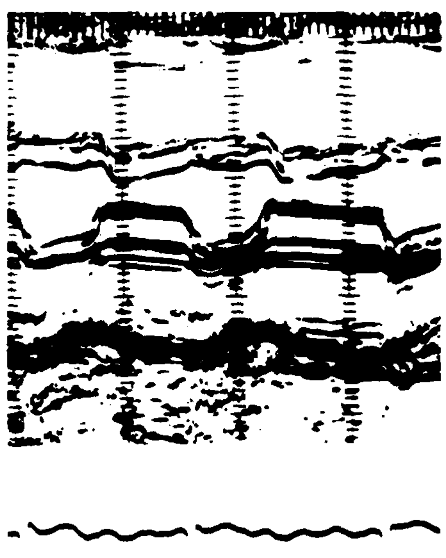


Figure 16

- reduction to a varying extent of the EF slope of the AMV.
- diastolic movement of the PMV in the same direction of the AMV (paradoxical or unison movement). These two signs are essential for the diagnosis and may be combined with a reduction or elimination of the A wave, the thickening of valvular echos or with LA abnormalities, the right cavities and the pulmonary semilunars reflecting the haemodynamic effects. The 2DE is also very sensitive and has the major advantage of detecting subvalvular changes allowing calculation of the mitral surface in the small axis section.

We should stress the difficulty of reaching a diagnosis on the basis of an isolated reduction of the EF slope without any accompanying reversal of the movement of the PMV. This may indicate:

- either an unusual myxoma of the LA: the TME presents other highly indicative signs and the 2DE and the angiocardiograph detect the tumor.

- or an obstruction to filling of the LV related to reduced sensitivity . The hypertrophy which is the cause and which should give echographic signs taking the form of a thickening of the walls, may be secondary to aortic stenosis, hypertension (diagnosed by the usual means) or may be primitive, in the context of a myocardiopathy which may give few clinical signs in early stages,

- some very mild mitral stenoses may also involve subnormal diastolic movement of the PMV.

b) Mitral incompetency (MI)

We should distinguish:

- TME and 2DE which are very useful in assessing the effects of mitral leakage but which do not establish the diagnosis except in some forms involving particular mechanisms (ballooning, tearing of the mitral chordae),

- and DPE, a sensitive and reliable method for positive diagnosis whatever mechanism is involved.

1) Mitral ballooning (BARLOW'S syndrome)

This syndrome is usually idiopathic and of genotypical origin and is of some importance in the expert examination of FP for three reasons:

- the variable clinical signs, which may be typical (mesotelesystolic click-murmur syndrome) or may be truncated (telesystolic murmur or isolated mesosystolic click) or may be absent permanently or intermittently;

- a development which is usually benign but with the possibility of rare, severe and sometimes unpredictable complications including ventricular arrhythmia (causing sudden death) and sudden or gradual increase in mitral leakage;

- the possibility of deterioration as a result from flight in high performance aircraft, of silent or well-tolerated mitral ballooning due to acceleration (rhythm disturbances, creation or increase of mitral leakage).

TM and 2DE Echocardiography provide diagnosis and detect forms which are silent during auscultation.

In TM, two abnormalities establish the pathology and may be observed alternately in the same patient by slight changes in the siting of the transducer:

- the telesystolic dome pattern (figure 17A): a sudden backward movement of one or both valves during mesotelesystole, followed by a rapid return to the protodiastolic closing point D. This is often combined with a slight forward movement during protosystole which is similar to the SAM pattern described for obstructive myocardiopathy.

Figure 17A

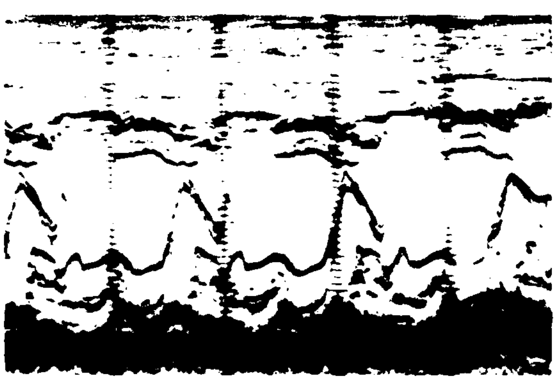


Figure 17B

- the pansystolic hammock picture (figure 17B): the gradual backward movement of both leaflets, beginning in protosystole, peaking in mesosystole, with a gradual return to point D.

The method of investigation must be rigorous and standardised otherwise false pictures suggesting ballooning will be obtained in normal subjects (hammock picture resulting from poor siting of the transducer). Other much less typical abnormalities are noted only if confirmed by 2DE. TME also visualises anatomical abnormalities of the valves which are supple but have several layers (valvular vegetation).

Real time ultra-sound definitely increases the specificity and sensitivity. This method makes it possible to confirm or infirm some minor or debatable patterns picked up in TM. The sagittal section along the main LV axis is the incidence to be preferred: without going into details we draw attention to the fact that the main diagnostic criterion is the demonstration of bulging of one or of both leaflets towards the left atrium, the most posterior point on the convexity projecting a small or large distance beyond the plane of the mitral ring. This long axis section makes it possible to assess the extent of ballooning:

- from forms at the limit of normality, the significance of which may be debatable but which may sometimes take on the typical characteristics during amyl nitrite inhalation,

- right up to severe forms with complete eversion of one of the two leaflets into the LA and these conditions are really mitral prolapse some of which may result from tearing of the chordae.

In some patients the four cavity section gives better visualisation of ballooning and of an eversion of the valves.

2) Tearing of the chordae

This results in major mitral incompetency which is clinically apparent and totally incompatible with any aeronautical activity. We will therefore discuss this topic only briefly even though it can be diagnosed and assessed by means of echocardiography.

TME reveals the volume overload of the LV resulting from the haemodynamic effects and a combination of direct signs which are grouped differently depending on the leaflet involved:

- diastolic signs affecting the AMV (very long pathway, cross vibrations, multiple parallel or criss-crossing echos) or the PMV (reversed movement during protodiastole, at times completely chaotic).

- systolic signs with a hammock or telesystolic couple picture.

2DE in the major axis and four cavity sections gives further information and in particular demonstrates systolic eversion into the LA of one or sometimes both leaflets.

3) Other mitral valve abnormalities

TME and 2DE may sometimes determine the mechanism by detecting vegetations (more clearly seen in 2DE) or by establishing arguments suggesting associated MR. Usually only indirect signs of volume overloading of the LV are detected, these signs are not specific and may be totally absent in mild MI, those cases precisely in which the diagnosis is debatable.

Pulsed Doppler Echocardiography may establish a diagnosis of MI due to whatever mechanism even though the systolic murmur may not be clear. If the Doppler window is correctly sited in the LA, behind the AMV, the characteristic holo-systolic turbulent flow is visualised (an appearance similar to that shown in figure 11B for the tricuspid). In experienced hands this method gives reliable results except in the case of very mild MI with a localised flow or a flow in a specific direction.

c) Aortic stenosis (AS)

TME demonstrates two types of abnormality. Indirect signs of pressure overloading of the LV are present only in fairly tight or long established stenoses which are bound to be detected on clinical examination. Direct signs include changes in the semilunar valves: diastolic thickening of the valvular echo and, an unreliable sign since it depends on the incidence of the beam, diminution of semilunar opening. A whole series of intermediate stages are possible between major changes, such as transformation of the valvular apparatus into a mass of echos, to signs which are difficult to identify and a sub-normal

picture in the case of mild AS with supple valves precisely the case which poses diagnostic problems during the expert examination). Sometimes the examination may suggest congenital etiology (signs of a bicuspid valve, or suggesting sub-valvular AS, which is very unusual in the adult).

2DE is much more accurate and sensitive both along the sagittal main axis section and in transverse sections at various levels. This examination demonstrates concentric hypertrophy of the LV, valvular changes, diminished semilunar opening and can be used to calculate the area of the aortic orifice.

d) Aortic regurgitation (AR)

Diagnosis is essentially clinical, however mild forms may pass unnoticed during auscultation, especially when the heart beat is rapid. The haemodynamic effects must also be investigated since their absence would militate in favour of an exception being made during the career of the individual. Echocardiography is useful both for diagnosis and for investigating repercussions.

Demonstration of volume overloading of the LV by TME and 2DE establishes the considerable haemodynamic effects of AR, which have already been described from a clinical point of view.

TME provides reliable and sensitive positive diagnosis by visualising high frequency diastolic vibrations of the AMV (fluttering). If leakage is considerable, these vibrations may extend to the septum and to the PMV (figure 8). This sign is absent only in very mild AR with a particular direction of the regurgitation flow or if the mitral valves are very severely affected (associated MR).

PDE is even more sensitive than the TM mode to the extent that the signs it detects are not affected by the condition of the mitral valve: the Doppler window being placed between the semilunars, diastolic turbulence is detected in cases of AR. The risk of confusion between the flow obtained between AR and the transmitral diastolic flow of MR is avoided if the Doppler window is correctly sited.

The mechanism of AR may be established by TME or PDE which may show alteration of the semilunars, vegetations, bicuspid valves, prolapse of one semilunar into the LV, or considerable dilatation of the incoming aorta.

e) Other abnormalities of the valves

Such abnormalities are rarely encountered in FP and we will not discuss them. We will simply recall that TME and 2DE can be used for the diagnosis of tricuspid stenosis and that PDE is the best examination for the diagnosis of TI.

Mild stenoses of the pulmonary orifices which are devoid of haemodynamic effects are the only type of pathology affecting the pulmonary arteries likely to be met with during the expert examination of FP and they occur only during the admission examination. Unfortunately in these mild forms echocardiography cannot be relied upon to detect them.

Figure 18

III.2.b Primitive myocardiography

The primitive conditions affecting cardiac muscle are one of the major indications for echocardiography which can provide the following:

-early diagnosis and classification of the various forms,

-exact evaluation of myocardial function, deterioration of which may be an initial sign coupled with disturbed ventricular rhythm or a slightly enlarged heart shadow,

-echography may also establish the absence of any valvular , ischaemic or congenital heart disease as the source of myocardial dysfunction.

a) Congestive or dilated forms

TME DIAGNOSIS is obvious in advanced forms (figure 15) based on the association of LV dilatation, overall hyperkinesia, marked reduction of the ejection index and the VCF, and changed thickening index of the heart wall. There are signs of reduced flow at the aortic semilunars and the appearance of the mitral valves is characteristic: a small electrical mitral valve clearly visible but surrounded by a huge ventricular cavity.

2DE demonstrates the overall harmonious hyperkinesia and argues against any ischaemic cardiopathy (unless this presents tight stenoses of the three coronary artery trunks).

IN INCIPIENT FORMS, which may be encountered during the expert examination of FP, echocardiography can contribute to the diagnosis by demonstrating a diminution of the myocardial function indices and a slight dilatation of the LV, these signs are significant if isolated and accompanied by homogeneous contraction. THis is why TM and 2D echography is essential in the case of rhythm disturbances, apparently isolated electrocardiographic abnormalities or mild cardiomegaly.

b) Hypertrophic forms (HMC)

Echocardiography is essential for their diagnosis. This method contributes to their analysis and is able to distinguish between diffuse or symmetric forms (SHMC) and segmental or asymmetric forms (AHMC) as well as between obstructive forms. The method establishes that left intra-ventricular dynamic obstruction of muscular origin is much more frequent (though not always present) in asymmetric forms and may sometimes be present in diffuse forms.

- TM Echocardiography:

The various forms of HMC have in common hypertrophy of the walls with reduced left ventricular diameter, the impairment of contractility of the wall is reflected by changes in the thickening indices, a relative constancy of the ejection index and of the VCF, as well as by early impairment of diastolic function reflected in a reduced EF slope of the anterior mitral valve leaflet.

DIFFUSE OR SYMMETRIC HMC corresponds to the abnormalities described above. Their diffuse nature is reflected in a septal thickness over posterior wall, thickness ratio of less than 1.3. The picture is very similar to that found in concentric hypertrophy of the LV secondary to aortic stenoses and to hypertension.

The main sign of SEGMENTAL HMC is asymmetric septal hypertrophy (ASH) characterised by isolated or predominating thickening of the septum (DTS/DTPW ratio greater than 1.5). Septal hypokinesis contrasts with normal or increased kinetics of the posterior wall. There is frequently a protodiastolic striking of the AMV against the septum (the mitral apparatus, being further forward than normal, is confined within a small LV). However, ASH is not specific and may occur in various forms of pressure overloading of the LV and in some congenital heart conditions. TME may also lead to false positive and false negative conclusions, the method may fail to recognise septal hypertrophy in the apex or conversely suggest a diagnosis of ASH when due to particular orientation of the LV the ultrasonic beam crosses the septum obliquely. The right side of the septum may often be difficult to identify and this hinders interpretation.

DYNAMIC OBSTRUCTION OF THE LV, is a characteristic syndrome of the AHMC. This produces two signs. Anterior mesotelesystolic movement of the mitral valve (SAM) is considered to be significant if it reaches 20% of the empty chamber (figure 19A). This movement may sometimes be much greater, going as far as to actually touch the septum. Partial mesosystolic closing of the aortic semilunars followed by partial or complete reopening is the second criterion of obstruction (figure 19B).

Figure 19A

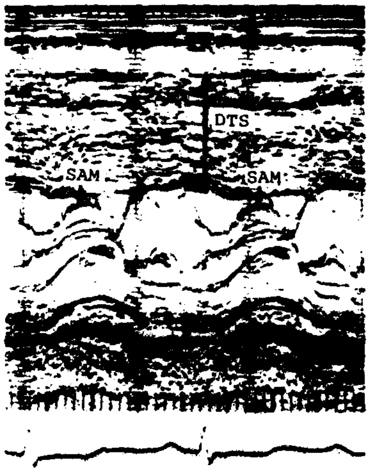
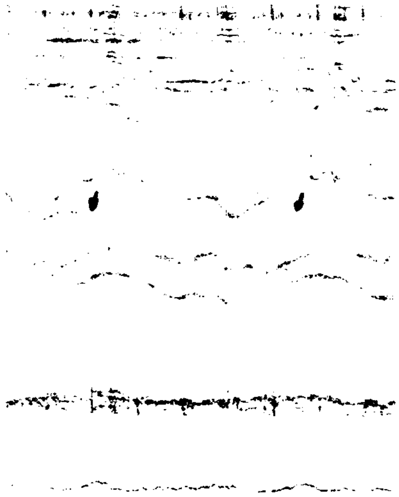



Figure 19B



These two signs are in no way specific. SAM is observed in other forms of aortic obstruction, in mitral ballooning, in the hyperkinetic heart and in cases of abundant pericardial effusion. Mesosystolic closing of the semilunars reflects only an obstacle on the ejection pathway.

However, TME detection of the combination of ASH, SAM and mesosystolic closing of the semilunars does establish the diagnosis of obstructive myocardiopathy.

It should be noted that the obstruction syndrome may not be present in the basal condition and may be detected only during pharmacological tests (Isuprel, amyl nitrite).

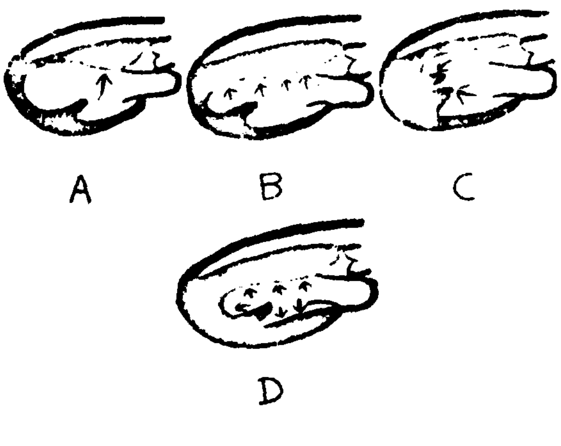
- 2D Echocardiography:

This technique is particularly useful in this indication, and corrects for any error of axis in TME (false ASH), as well as detecting some forms of segmental hypertrophic myocardiopathy which are not detected by TME as well as determining the mechanism of the obstruction.

Major axis, minor axis and 4 cavity sections make it possible to detect and classify the various forms of asymmetric HMC (figure 20):

- septal hypertrophy extending beyond the pillar zone
- forms limited to a sub-aortic septal ridge
- forms situated in the apex, usually not detected by TME.

Figure 20



These sections visualise any obstruction present and explain the mechanism behind it: the obstruction results essentially from the pillars and the sub-valvular apparatus, very secondarily that of the tip of the AMV (figure 21).

Thanks to echocardiography and particularly to 2DE, more and more frequently sub-clinical forms of HMC are being discovered at an early stage. The progressive danger of typical obstructive HMC is well known. The danger posed by apical and non-obstructive hypertrophic forms are less well established and the discovery of such forms will doubtless pose difficult problems in the expert examination of FP.

c) Restrictive forms

Primitive restrictive myocardiopathies consist essentially of endomyocardial fibroses . Such conditions are rare in our part of the world. Echocardiography may be useful in their diagnosis.

Figure 21


III.2.c Ischaemic heart disease

Development of 2DE has constituted a real step forward in this indication.

During an aorto-apex scan, TME can investigate the full length of the septum. The detection in isolation or in association with hyperkinesia of the posterior wall of septal hypo- or akinesia is an argument in favour of tight stenosis of the anterior interventricular artery. Similarly the presence of an isolated dyskinesia of the postero-lateral wall, which is also well visualised, may suggest significant stenoses of the right coronary and/or the circumflex.

However the TME has many limitations: failure to detect dyskinesias in the apical or antero-lateral region, the non-specific nature of abnormalites of septal kinetics, major errors in the overall assessment of left ventricular function from the diameters in the case of segmental abnormalities of contraction and the impossibility of distinguishing in the presence of dilatation and global hypokinesia between primitive myocardiopathy and ischaemic cardiopathy affecting all three trunks.

2DE because of the numerous sections which can be used makes it possible to study all the walls of the LV including the apical region. It readily visualises any segmental abnormalities of contraction and provides accurate evaluation of left ventricular function in the coronary artery disease patient.

However it should be remembered that a normal echocardiogram in no way refutes a diagnosis of coronary arteritis. Only positive results are of significance.

III.2.d Other indications for echocardiography

There are many and some are of special interest but most of little importance for the expert examination of FP. We will mention only three:

a) Pericardial effusions

The sensitivity of TM and 2D echocardiography in the detection of pericardial effusions was demonstrated some time ago. It is also known that this test can provide a rough assessment of the extent of effusion. However it is unusual to detect pericardial effusion in the exploration of isolated and asymptomatic cardiomegaly: a problem which may sometimes occur in the expert examination of FP. We will simply recall a classical diagnostic trap: in normal subjects a slight systolic separation between the epicardium and the pericardium may frequently be detected and this has no pathological significance.

b) Congenital heart disease

Apart from valvular conditions already mentioned, the only congenital heart conditions likely to be detected in flying personnel (during the admission examination) are atrial or ventricular septal defects with moderate shunt flow which is well tolerated.

Little is to be hoped from ultra-sound in mild forms of atrial septal defect (ASD). The signs of volume overload of the RV, with no specificity are detected only in fairly massive ASD. 2DE which is more reliable in assessing the volume of the RA and the RV does not detect the septal defect in the four cavity section unless this fairly massive.

Similar remarks also hold for VSD. Volume overload of the LV, dilatation of the LA and the RV occur only in the case of fairly considerable shunts which are unlikely to have been unnoticed prior to the expert examination. 2DE does not visualise the septal defect unless this is considerable and situated high up. The Pulsed Doppler may establish the diagnosis in some cases by detecting evidence of turbulence to the right of the septum.

c) Rhythm and conduction disturbances

Abnormalities of septal movement have been described during the complete left bundle branch block and type B WPW syndromes. These are of little diagnostic interest and the purpose of echocardiography is more likely to be the investigation of causative or associated heart disease.

## IV / APPLICATION TO THE EXPERT EXAMINATION OF FLYING PERSONNEL /

We will now consider the practical modalities of the application of echocardiography to the expert examination of flying personnel.

### IV.1 Selection of apparatus

It is essential that an examination combining the TM and 2D modes be carried out since, as we have shown before, the two methods are complementary.

Pulsed Doppler Echocardiography is definitely an interesting addition in the diagnosis of valvular regurgitation particularly of tricuspid incompetence and some forms of ventricular septal defects. However, these indications are relatively restricted in the expert examination of FP. Furthermore this type of examination is lengthy and requires a highly experienced technician and these considerations explain why the PDE remains limited to a few highly specialised laboratories.

The addition of a micro-computer saves time in the interpretation of the recordings, and also increases the possibility of quantitative echocardiography, particularly in the evaluation of left ventricular function. However it should be remembered that the indices provided remain dependent on the quality of the echographic recordings and on the soundness of the operator's selection. Experience has also shown that in clinical practice the single indices of left ventricular function provided by the manual interpretation of the recordings are sufficiently discriminating.

### IV.2 Indications for ultra-sonic examination

#### IV.2.a Routine echocardiography

Should flying personnel be routinely submitted to ultrasonic examination in the absence of any special sign and if so under what conditions?

a) Systematic admission ultra-sound

In theory this is an attractive proposal but it is not realistic. Echocardiographic examination would doubtless result in the detection of some minor heart diseases which escape the routine clinical and paraclinical examinations and which in the long run may develop so as to threaten both air safety and the career of the subject involved. The idea is also attractive from an epidemiological and prognostic point of view concerning heart conditions, the frequency and development of which remain unclear (symptom-free mitral ballooning, incipient forms of hypertrophic myocardiopathy).

*On the other hand* it should be pointed out that a complete echocardiographic examination is relatively lengthy and is not suitable for the examination of a fairly large number of subjects within a limited time. Furthermore it is almost certain that the gains from such an approach would be limited and that air safety would gain little.

This is not the case however if this routine electrocardiographic screening is limited to certain types of flying personnel exposed to a maximum of aeronautical risk factors such as pilots of high performance aircraft or astronauts. The severity of the acceleration to which these individuals are subjected justifies screening for infra-clinical heart conditions which may be aggravated by flight and which may also threaten air safety. This particularly concerns mitral ballooning and mild forms of hypertrophic myocardiopathy and possibly for obstructive conditions known for their propensity to disturb rhythm.

b) Routine echocardiography during professional life

This would seem desirable only for the most highly exposed categories of personnel, particularly with the intent of screening for ischaemic cardiopathy. It remains to establish the intervals and/or age at which such routine examinations should take place. We should also draw attention to doubts concerning the value of echocardiography in the detection of latent coronary failure.

IV.2.b Guided echocardiography

It is certain that echocardiography is valuable in two types of situation:

a) In the case of a well characterised cardiovascular abnormality

Echocardiography should be included amongst the examinations intended to determine the repercussions of such a condition if there is to be any question of maintaining,even in limited form, fitness for flight. The absence of echocardiographic signs of left ventricular overload, associated with normal myocardial performance indices constitute a highly favourable element if combined with moderate hypertension, mitral or aortic regurgitation considered slight on the basis of a clinical electrocardiographic radiological or phonomechanographic criteria.

In subjects whose fitness is maintained, the regular performance of ultra sound examinations may detect earlier than routine paraclinical examinations the first signs of left ventricular distress taking the form of a progressive change in the ejection index and the VCF.

b) Diagnostic aid in some circumstances frequently encountered during the expert examination of FP.

EQUIVOCAL SYSTOLIC MURMURS: These are small partial murmurs which may be protosystolic, protomesosystolic (even mesosystolic), they may also be variable and are generally sited over a fairly widespread left latero-sternal region. Usually such murmurs are without pathological significance. In doubtful cases ultra-sound should be routinely requested in the same way as phonomechanographic examination. The examination has the major advantage of permitting the total exclusion of obstructive hypertrophic myocardiopathy as long as it is combined with a phonomechanogram and with pharmacological tests since the dynamic obstructive syndrome may not be present in the basal state.

ISOLATED MESOSYSTOLIC CLICK: An isolated apical telesystolic murmur may initially suggest MR and the association of a telesystolic click-murmur suggestive of mitral ballooning with leakage, one should however, remain reserved in the interpretation of isolated mesosystolic clicks. Echocardiography makes it possible to visualise mitral ballooning. Pharmacodynamic tests and the phonocardiogram are essential even when the ultra sound is normal : they alone can confirm or infirm the presence of mitral leakage. It is only when all results (ECG, radiology, ultra-sound and phonomechanography with methoxamine and amyl nitrite tests) are normal that the absence of any pathological significance of the click can be included and the condition described as asynchronic mitral closing.

DISCOVERY OF MODERATE CARDIOMEGALY: The problem frequently arises of the discovery of a cardiac shadow of fairly limited size during radiology. Echocardiography may provide useful diagnostic information:

- not so much suggesting valvular disease,(which is unlikely to have failed to be detected by routine examinations if it has given rise to enlarged heart) or to chronic pericardial effusion (which is very rarely detected in the absence of suggested signs),
- but particularly suggesting infra-clinical incipient myocardiography.

In highly athletic subjects (who often also present slight electrocardiographic abnormalities), left ventricular hypertrophy-dilatation is associated with

a very forceful contraction immediately visible on the TM echocardiogram and confirmed by high values of the performance indices, a situation very different from that of incipient myocardiography.

APPARENTLY ISOLATED ECG ABNORMALITIES: Primary disturbances of repolarization cause the problem of latent coronary arteritis, but may be symptomatic of cardiopathies with signs which are poorly or variably detected by auscultation (mitral ballooning, mitral myocardiopathies) or which may be encountered in normal or in strong subjects in order not to overlook one or other of these conditions. The examination may sometimes provide indirect information suggesting coronary failure but it should be remembered that a normal echocardiography cannot be used to refute such a diagnosis.

Frequent ventricular extrasystoles also require echocardiography for the screening of the same conditions. Furthermore this examination is also essential in the presence of supra-ventricular paroxysmal tachycardia, flutter or paroxysmal atrial fibrillation.

In the presence of partial right bundle branch block, echocardiography is not required to confirm cardiac integrity if the patient is young, asymptomatic and, particularly, athletic.

However, the examination is required in cases of complete right bundle branch block or left bundle branch block, both of which may often be symptomatic of hypertensive or primitive ischaemic myocardiopathy. It should be remembered that in the case of complete left bundle branch block the displacement of the septum is abnormal on the echocardiogram.

Pre-excitation syndromes including short PR, also justify recourse to echocardiography since they may sometimes be associated with heart diseases which may pass unnoticed. This is the case for some types of myocardiopathy or of mitral ballooning (the latter abnormality may be secondary to pre-excitation).

IN CONCLUSION

The various modalities of echocardiography provide a valuable aid in the expert examination of flying personnel. This technique should be added to the list of non-invasive explorations suitable for flying personnel, since the examination does not replace but complete the other methods. Apart from special cases mentioned in the text it would not appear that echocardiography should be used routinely but only in the presence of certain common cardiological problems which it may help to solve.

CAPTIONS OF THE FIGURES

FIGURE 1 One dimensional echocardiography : A, B and TM modes

AW : anterior wall
PW : posterior wall
S : septum
AMV : anterior mitral valve
PMV : posterior mitral valve
RV : right ventricle
LV : left ventricle
Ao : aorta
LA : left atrium
US : direction of beam

FIGURE 2 Real time echocardiography

1. Multiscan
2. Sectorscan (after LESBRE)

FIGURE 3 Usual incidences (after FEIGENBAUM)

AMV : anterior mitral valve
PMV : posterior mitral valve

FIGURE 4 Transmitral incidence

DE : maximum opening amplitude of the AMV
EF : rapid protodiastolic closing
A : telediastolic reopening (atrial systole)
CD : systolic phase
En : Endocardium
Ep : Epicardium

FIGURE 5 Aorta-LA incidence

Inf : pulmonary infundibulum
SO : semilunar opening
SC : semilunar closing
Q-SO: pre-ejection period
SO-SC : ejection time

FIGURE 6 Sub-mitral incidence

DD : telediastolic diameter
SD : telesystolic diameter
DT : telediastolic thickness
ST : telesystolic thickness
Mc : mitral chordae
TD : telediastole
TS : telesystole

FIGURE 7 Apex-Aorta scan

FIGURE 8 2DE major axis section

A : diagram of the structures visualised in this incidence
B : normal 2D echocardiogram

FIGURE 9 Minor axis sections

A : structures visualised in function of the section planes
1 - through the major vessels
2 - through the mitral valve
3 - through the pillars
(PI: pulmonary infundibulum; TV: tricuspid valve; P: posterior mitral pillar; A: anterior mitral pillar)
B : section through the mitral valve

FIGURE 10 Apical incidences

A : 4 cavity section
ATV : anterior tricuspid valve
B : LV-LA section

FIGURE 11A Pulsed Doppler Echocardiography: recording of the normal transcuspid flow

Doppler window (W) is behind the anterior tricuspid valve (ATW). The Doppler spectrum graph (SD) shows a normal flow during diastole (D) and the absence of flow during systole (S)

FIGURE 11B PDE

The Doppler window is placed behind the tricuspid
Holosystolic turbulence in the RA (arrow).

FIGURE 12 Volume overload of LV

Extended pathway of the septum (S) and of the posterior wall (PW)

FIGURE 13 Pressure overload of LV

Considerable increase in the thickness of the septum and of the posterior wall
Reduced EF slope of the AMV

FIGURE 14 Volume overload of RV
Dilatation of RV: paradoxical septum (arrow)

FIGURE 15 Congestive myocardiopathy
Hypokinesia of the walls; left ventricular dilatation (DD = 75 mm); small mitral with low flow (arrow)

FIGURE 16 Tight mitral stenosis and alteration

FIGURE 17 Mitral ballooning

A : telesystolic bulge
B : pansystolic hammock

FIGURE 18 Aortic incompetence
AMV fluttering

FIGURE 19 Obstructive myocardiopathy

A: Mitral incidence: SAM of nearly 100%; septal collision of the AMV; considerable increase in septal thickness

B: Aorta-LA incidence: Mesosystolic closing and vibrations of the anterior semilunar (arrow).

FIGURE 20 Appearance of hypertrophic myocardiopathy in 2D Echography

A: sub-aortic septal ridge
B: widespread septal form
C: apical form
D: diffuse symmetric form

FIGURE 21 Major axis sagittal section
Considerable septal hypertrophy partially blocking the left ventricular cavity.

# CHAPTER 8

## EXPLORATION OF ARTERIAL FUNCTION USING DOPPLER FLOW DETERMINATION

## APPLICATION TO AERONAUTICAL AND SPACE MEDICINE

by A. Didier, H. Ille, C. Ribadeau-Dumas, Ph. Lantrade et Ch. Hiltenbrand*

Since initial studies by Japanese researchers in the 1960's (SATOMURA; KATO), the use of the Doppler effect to determine the rate of blood flow through the vessels (flow determination or velocimetry) has been widely and successfully developped, particularly in France. It has become a routine examination in angiology.

The accuracy of the data obtained and the total lack of risk of the method suggests that it should have a place in aeronautical and space medicine, in the medical examination of flying personnel and the investigation of physiological changes of arterial flow in the body during current aeronautical and space pressures.

### PRINCIPLE OF THE METHOD

The Doppler-Fizeau effect is a change in frequency of a vibration when the source moves relative to the observer.

The Doppler ultrasonic determination of the blood flow rate makes use of this principle by determining the change of frequency (delta F) of an ultrasonic beam directed onto the vessel under study. The beam is reflected by solid elements within the blood, the flow rate of which is the same as that of the bloodstream as a whole. The change of frequency is a function of the blood flow but also of the angle (theta) of incidence at which the ultrasonic beam strikes the vessel (figure 1). The data obtained is in the form of a velocity and its exact determination depends on knowing the angle theta.

Calculation of the blood flow rate depends on determination of the cross-section of the vessel.

### INSTRUMENTS USED

1) Continuous ultra-sound emitting instruments

These are the simplest, least costly and most effective. They are used in routine daily practice.

- some are simple ultrasonic stethoscopes, consisting of a probe which both emits and detects ultra-sound and of a stethoscope connected to a black box. This type of apparatus may be completed by a recorder providing a permanent record in the form of a chart. This type of equipment is not able to determine the direction of blood flow relative to the probe (non-directional instruments).
- directional flow determining instruments are more widely used in practice. Exploration of the artery makes use of a pencil-probe the tip of which bears two crystals, the one an emitter and the other a receiver. Present instruments have two interchangeable probes, the one with a 4 MHz frequency and the other with an 8 MHz frequency, which provides a wide range of effectiveness with respect to the depth of the vascular flow investigated. After filtering and amplitude demodulation, the signal received corresponds to the difference between the emitted frequency and the reflected frequency. This is made audible by means of a loudspeaker, or visible on a galvanometer, or sometimes recorded in the form of a velocity chart on heat sensitive paper.

This apparatus is directional: by means of a phase detector and a differential system the exit signal is either positive or negative depending on the direction of the velocity vector relative to the probe.

Because of lack of information concerning the angle theta and the cross-section of the vessel, the information available is limited to an approximation of the speed of solid elements within the blood of the vessel investigated opposite the probe.

2) Pulsed emission instruments

These instruments seek to overcome these limitations at a cost of a considerable increase in instrumentation, handling difficulties and cost. They aim to provide an accurate determination of velocity and of blood flow in the vascular cross-section investigated.

There is no longer need to determine the angle theta because of a double emitting probe the crystals of which are at a fixed angle to one another. The measurement is taken only when the signals from the two transducers are perfectly symmetrical.

Emission takes the form of a series of ultrasonic waves and the measurement is taken in a window (an electronic gate) which is set at a fixed delay after the ultrasonic

* Work performed by the Clinique Médicale et de Pathologie Vasculaire de l'H.I.A. Professor HILTENBRAND

emission, as well as the duration of opening. The delay establishes the depth, the duration, and the thickness of the zone investigated. Scanning the whole cross-section of the vessel from one wall to another by means of a series of successive determinations, the diameter of the vessel is determined exactly. At each level the instantaneous and mean velocity of the solid elements within the blood is recorded and this provides a profile of the relevant velocities for a determination of the physical characteristics of the flow. Given the diameter of the vessel and the rate of flow of the blood, it is possible to calculate the local flow rate which is conveniently displayed by a computer.

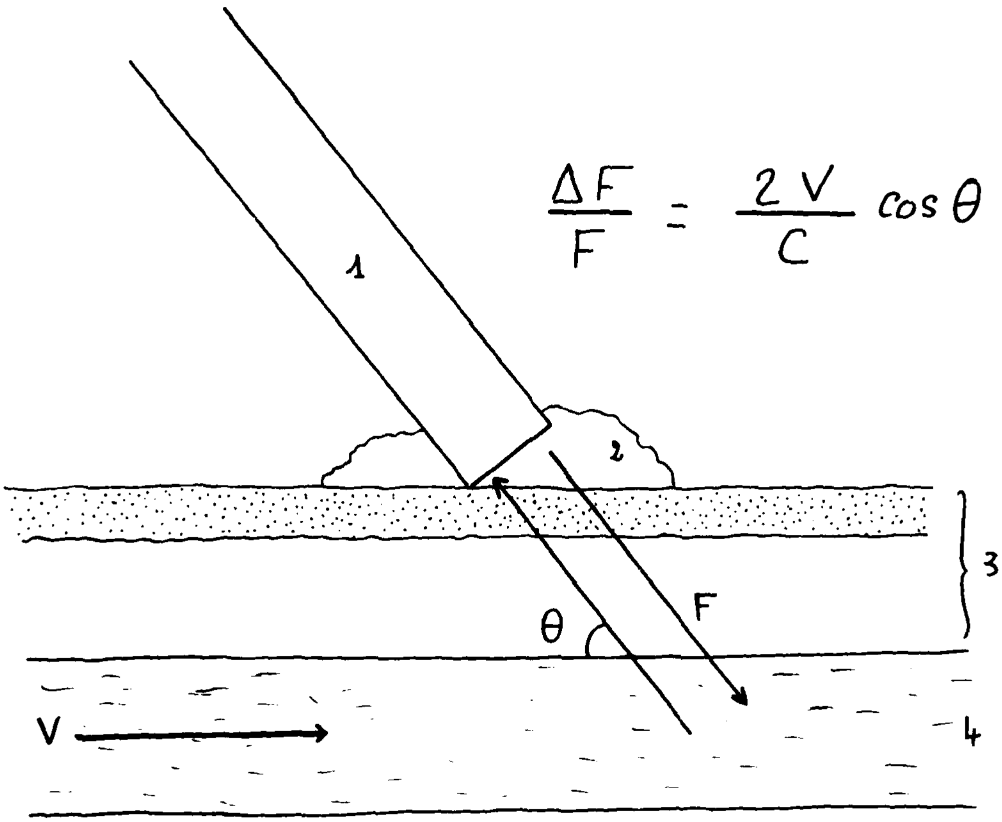



Figure 1
Principle of DOPPLER effect determination of blood flow rate

1 : Probe
2 : Contact paste
3 : Skin and surface tissues
4 : The vessel studied
delta F : difference between the frequency of the emission beam and of the beam being reflected from the vessel
V : velocity of the blood
C : velocity of ultrasonic propagation.

METHOD

The examination is always bilateral and symmetric and is carried out with the subject lying down.

1) Arteries explored

- In the cervico-cephalic region the sub-clavian arteries, brachiocephalic artery trunk, common and internal carotids, orbital ophthalmic arteries, and vertebral arteries can be explored together with the permeability of the communicating vessels of the Willis circle.
- In the arms, the sub-clavian axillary, humeral radial and cubital arteries, the palmar and interdigital arches and the arteries of the pulp can be investigated.
- The arteries of the legs accessible to this examination are the common, superficial and deep femorals, the popliteals, the anterior and posterior tibials, the peroneal and interosseous arteries and dorsal artery of the foot.
- In the abdomino-pelvic region it is sometimes possible to explore the aorta and the root of the digestive branches and common, internal and external iliac arteries.

2) The examination

This method requires a highly experienced operator if it is to be successful. Identification of the artery under study (on its anatomical pathway, from the signal obtained and from various distinguishing compressive manoeuvres) obtaining the best signal, detection of anatomical defects or abnormalities, obtaining a good recording, all require practice both in manoeuvres and in listening. This presupposes several months' practice and the carrying out of hundreds of examinations. This is even more true in the case of pulsed Doppler flow rate determinations which, it should be stressed, is still a research technique and restricted by two factors which are only temporary drawbacks:

- the first is the length and difficulty of the procedure. It requires 10-25 separate determinations to obtain a profile of the flow rate across an arterial section. The accuracy of these determinations depends on maintaining the correct position of the probe on the skin. "Multiple window" instruments will make it possible to obtain the profile of flow rate in a single determination and so simplify the procedure.
- the second is the excessive size of the double probe which makes it difficult to determine the flow in some arteries (in the neck and extremities in particular) It is greatly to be hoped that smaller double probes, fitted with an attachment system, will become available.

RESULTS

1) Continuous emission Doppler arterial angiography

This method is able to :

- determine the site of stenoses or obliterations, assess their functional importance and identify any replacement circuits called into play;
- assess the extent of peripheral arterial resistance downstream from the point investigated;
- detect loops, ectasias and fibro-muscular dysplasias;
- in the cervix, the method can be used to assess the functioning of the Willis circle and the basilar artery.

Some examples will make this clear:

Figure 2 shows normal artery flow determination records from the legs. In the records shown we can see:

A large positive primary systolic wave with a rapidly rising section and a more slowly falling section during which the blood flow rate slows and then ceases. These arteries supply a musculo-cutaneous territory and peripheral arteriolar resistances are high. The systolic wave is therefore followed by a negative, or reflux wave corresponding to the reversal of the blood flow. One or more positive and then negative waves of decreasing amplitude may follow, these vary depending on the elasticity of the arteries and the peripheral resistances. These oscillations of the curve reflect the restoration of the energy transmitted to the wall by the systolic impulse. The curve finally returns to the zero line corresponding to zero velocity, until the following systole. This is the pattern detected in all velocimetric curves for the arteries of the legs and arms with a dampening of the various effects towards the extremities.

Figure 3 shows an example of stenoses of the common femorals: tight on the right hand side, and mild on the left hand side.

- At the level of the stenosis, on the right there is a systolic reflux and a loud grating sound is heard. If it had been any greater, it would not have been possible to record the results. In less severe stenoses, there is either a dip in the systolic rise or a definite acceleration in the systolic and diastolic velocities. This is the case for the left common femoral.
- Downstream from the stenosis on the right there is considerable demodulation of the curves, they are spread out and the reflux waves have disappeared. On the left the downstream oscillations are virtually normal.
- Upstream from the stenosis there would be a reduction of the flow rate, spreading of the curve and the disappearance of secondary reflux waves.
- (Photograph 1) - Arterial angiography confirms this Doppler functional evaluation by revealing the expected anatomical lesions.

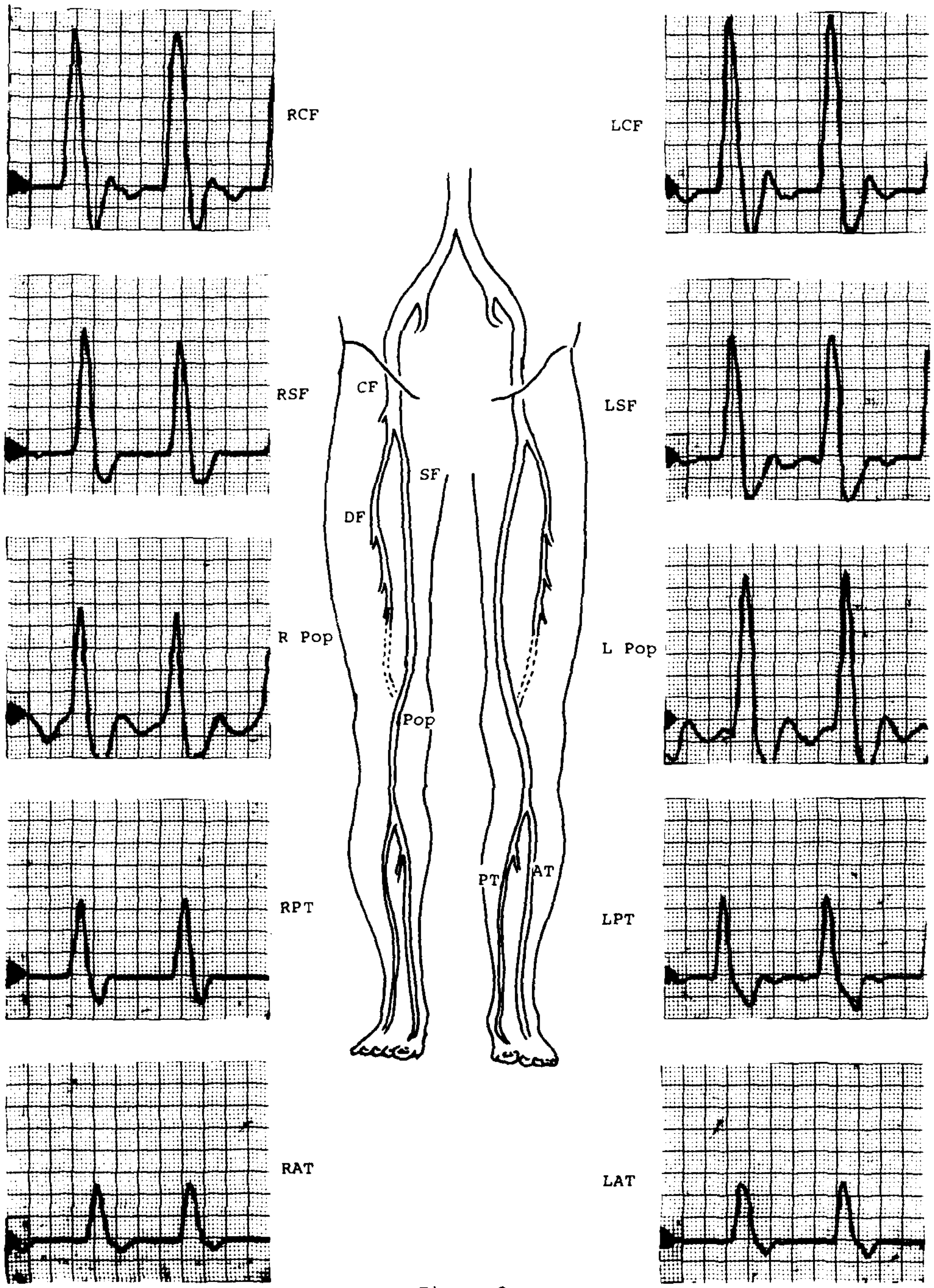



Figure 2

Doppler flow rate charts
obtained from the arteries of the legs

CF : *common* femoral
Pop: popliteal
AT : anterior tibial
The ▶ indicates the zero line

SF : superficial femoral
PT : posterior tibial
DF : deep femoral

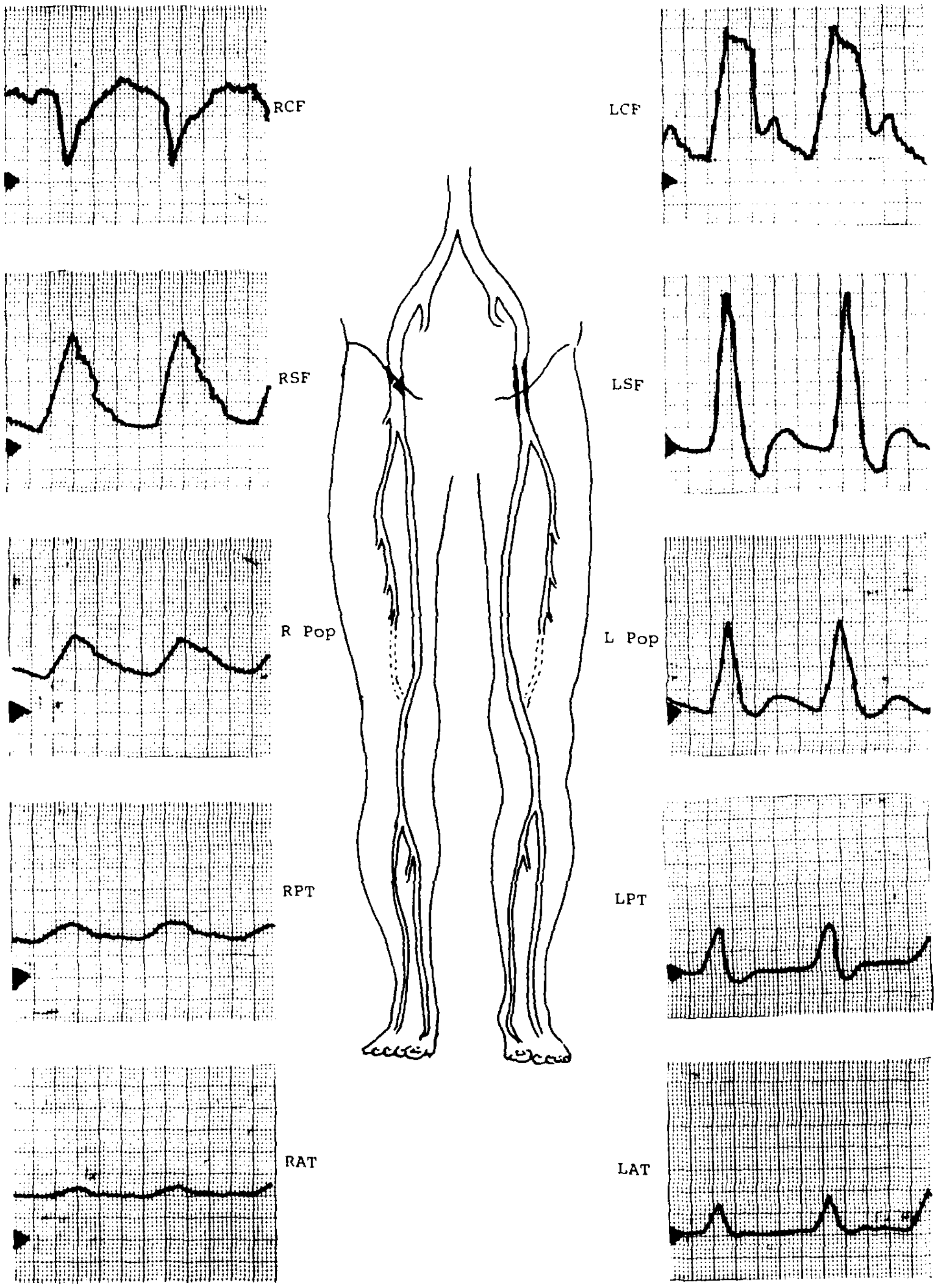



Figure 3

Stenoses
Tight stenosis of the right common femoral
Mild stenosis of the left common femoral

Photograph 1: Aorto-ilio-femoral arterial angiograph of the patient whose velocimetric study results are shown in figure 3.

Figure 4 shows the normal doppler results obtained from the cervical arteries. Arteries supplying the brain have very special velocity characteristics: since intra-cerebral peripheral arteriolar resistances are very low, the phenomenon of diastolic reflux disappears and there is a characteristic permanent diastolic flow.

The prevertebral section of the sub-clavian artery and the common carotid have a mixed distribution and present an intermediate velocimetric pattern. Anatomy, the presence of a musculo-cutaneous, cerebral or mixed distribution pattern, and various compression manoeuvres make it possible to distinguish between the sub-clavian artery, the brachio-cephalic arterial trunk, the common, internal and external carotids, the vertebral arteries and the branches of the ophthalmic arteries and also to investigate the permeability of the Willis circle and the basilar trunk.

Figure 5 is an example of the diagnosis of obliteration of the left internal carotid upstream from the ophthalmic artery and confirmed by arterial angiography (photograph 2 ). The following features can be seen on the velocimetric recordings:

- a reduction of the diastolic flow rate in the left common carotid (indicating a downstream obstacle);
- the absence of flow in the internal carotid;
- the reversal of the direction of blood flow in the ophthalmic, supplied by one or several branches of the external carotid and which irrigates the carotid syphon against the normal stream. As a result, the distribution territory of the external carotid becomes encephalic and the Doppler recording shows the increased diastolic flow.

Special cases:

Doppler flow determination provides an easy, low-cost and high safety method for the diagnosis of certain arterial, anatomical or pathological abnormalities.

- An arterial loop is probable if two identical streams are detected side by side but in opposite directions and which react in the same way to compression manoeuvres.

- Ecstasis is to be expected if there is a sudden slowing of the blood flow rate with large reflux waves and sometimes turbulence.

- An arteriovenous fistula is to be suspected if an excessive flow is detected in an artery and if this flow can be reduced by compression of the relevant territory.

- Doppler flow rate determination provides an elegant diagnosis of sub-clavian theft in cases of sub-clavian stenosis upstream from the root of the vertebral artery. In this case we find:

  - stenosis of the sub-clavian;
  - permanent reversal (or in some cases a reversal triggered by hyperaemia produced in the arms by the sudden tightening of an arm band) of flow in the homolateral vertebral vessel.

- Ultra-sound flow determination of the circulation in the humeral artery during various rotation-extension tests of the head and abduction of the arm provides clear evidence of any syndromes involving compression of sub-clavian in the thoraco-brachial section) (CALL and ROTH; ADSON and WRIGHT).

- As we have described, unusual flow patterns are detected in the extremities, either spontaneously or in response to cold, particularly for the interdigital arteries, in cases of Raynaud's phenomenon (1).

2) Pulsed emission arterial Dopplerography

This technique combines continuous emission ultra-sound flow rate determinations with determination of the diameter of the artery under investigation, drawing up of a velocity profile across this diameter, and the determination of the instantaneous and mean velocities at the point investigated. Hence it determines the arterial flow through the section studied.

The authors have reported initial results obtained in normal, athletic and arteritis subjects (2-3-5). We give a table showing the results from normal subjects.

Figure 6 shows the velocity profiles obtained from a carotid and femoral artery. The diastolic difference between the two flow patterns is clear. These profiles have the advantage of reflecting the type of blood flow which may be laminar, unstable or turbulent. (3-5-6-7)

REMARKS

1) Continuous emission ultra-sound flow determination is a reliable, accurate, and reproducible method for exploring peripheral arterial function. False positives or false negatives are rare (less than 5%) when the method is used by experienced operators. The method is totally non-invasive and is ideal for use in daily angiological clinical practice for the diagnosis and post-treatment monitoring of arterial disorders. This method obviously can be of value in several ways in the expert medical examination of flying personnel.

- During an admission expert examination, ultra-sonic flow determination is the best test for determining if a given clinical abnormality (apparent absence of the pulse, auscultation of an arterial murmur) is pathological or simply an individual variant of no significance.

- During service, if one or more vascular risk factors are present, what is important is not the metabolic abnormality but the presence or absence of arterial deterioration. Together with other methods of investigation, ultra-sound flow determination can provide valuable information: reduced arterial elasticity, presence of one or more intraclinical stenoses, increased peripheral arteriolar resistances, etc....

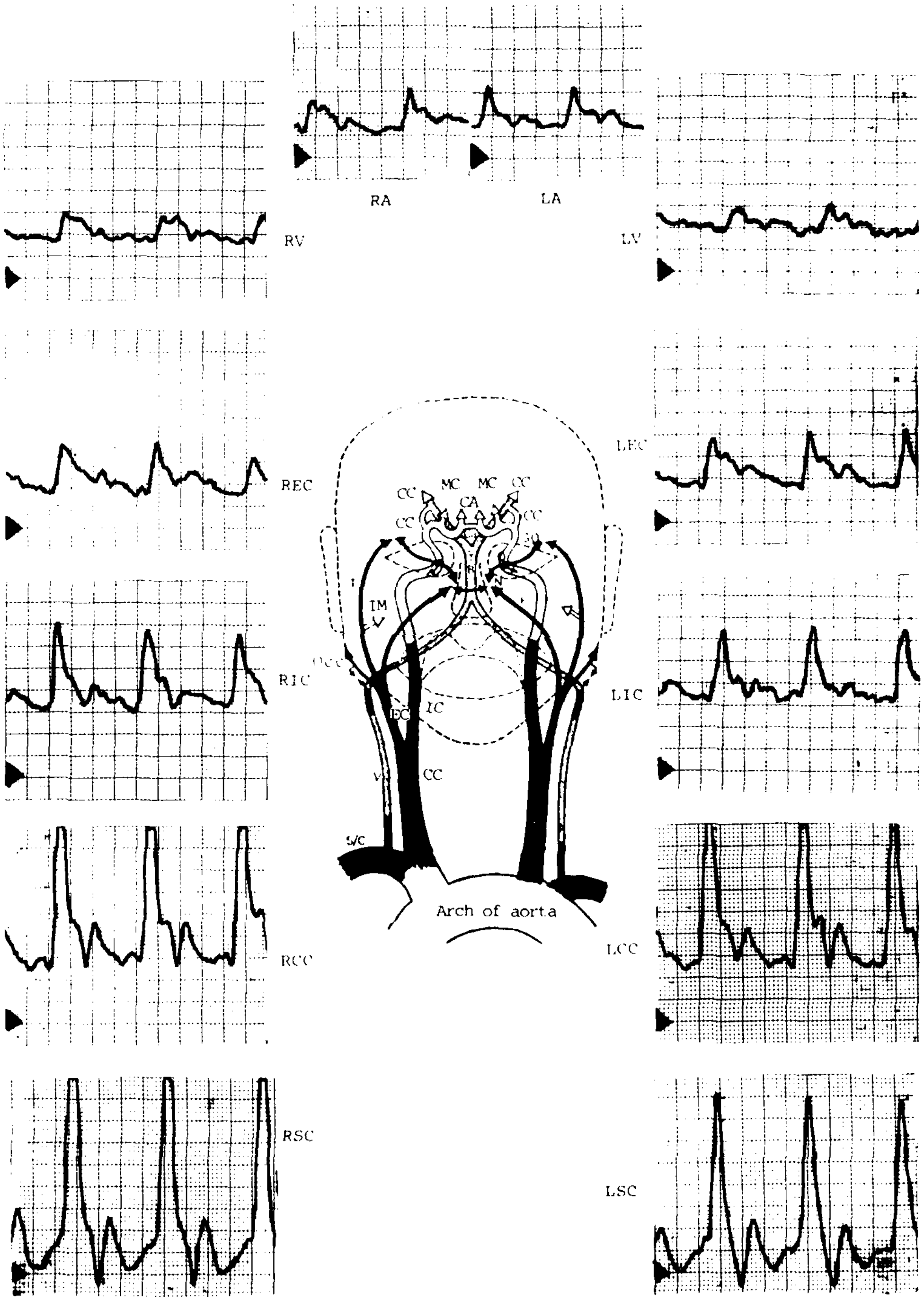



Figure 4 - Normal Doppler recordings obtained from the cervical and cephalic arteries

SC : sub-clavian
EC : external carotid
O : ophthalmic
IC : internal carotid
V : vertebral.

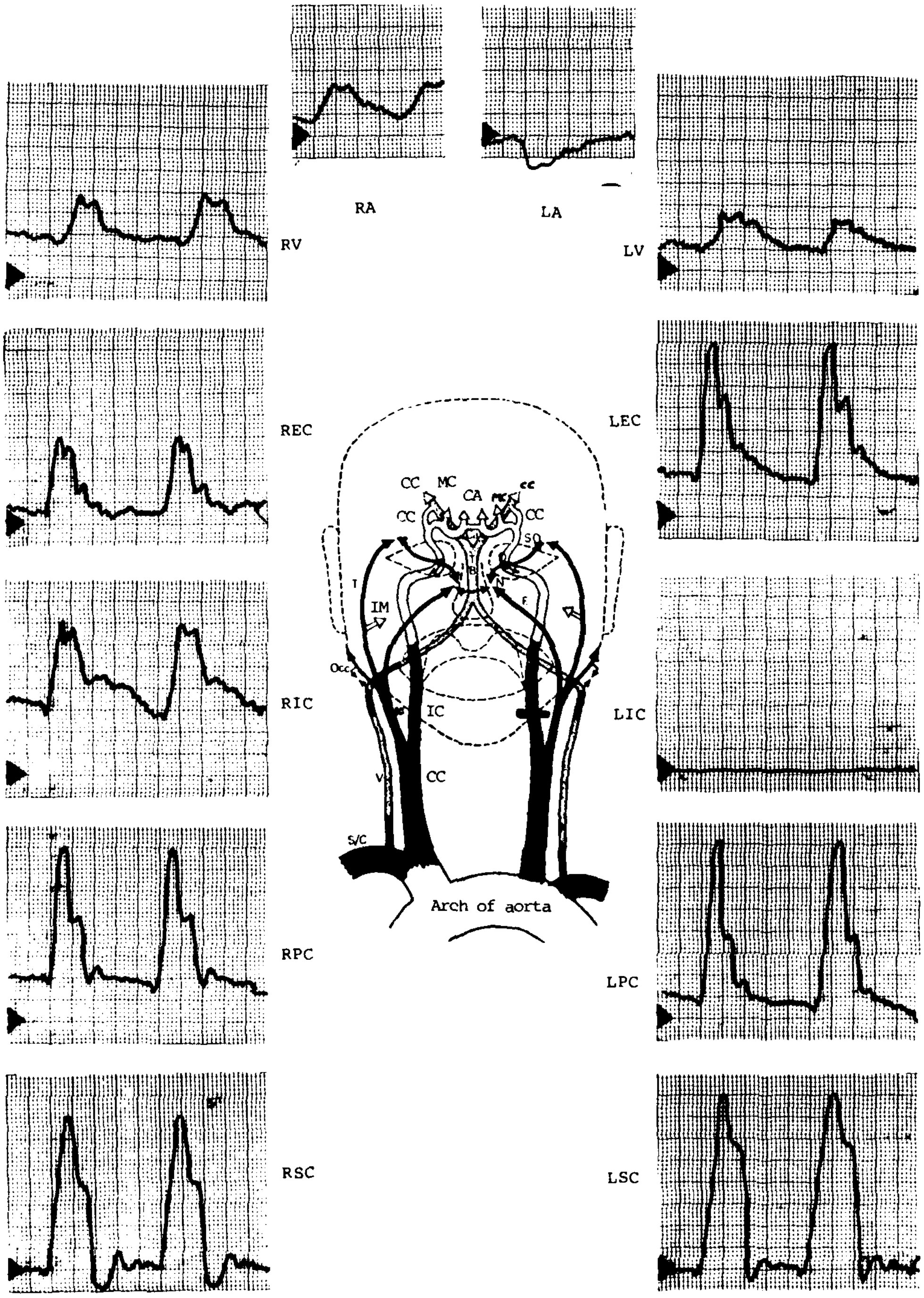



Figure 5 - Obliteration of the left internal carotid upstream from the root of the ophthalmic.

Photograph 2 - Arterial angiography confirming the obliteration of the internal carotid just after the bifurcation (same patient as in the flow rate records shown in figure 5).

- but particularly suggesting infra-clinical incipient myocardiograpny.

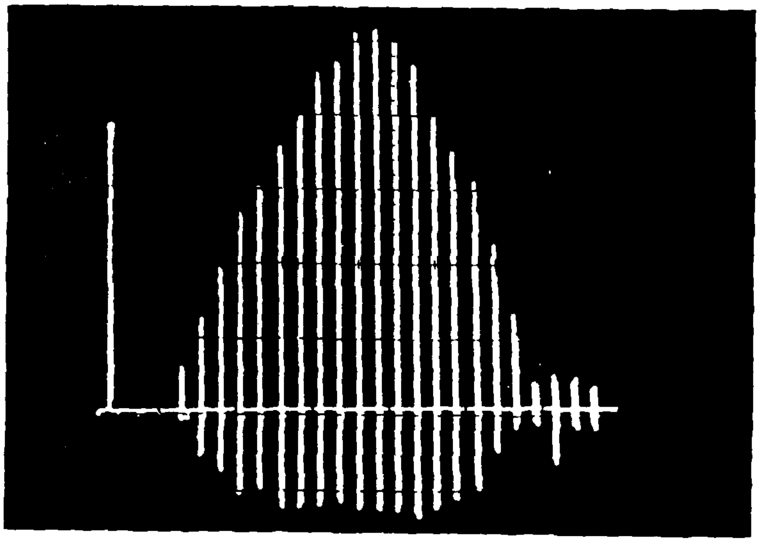
In highly athletic subjects (who often also present slight electrocardiographic abnormalities), left ventricular hypertrophy-dilatation is associated with



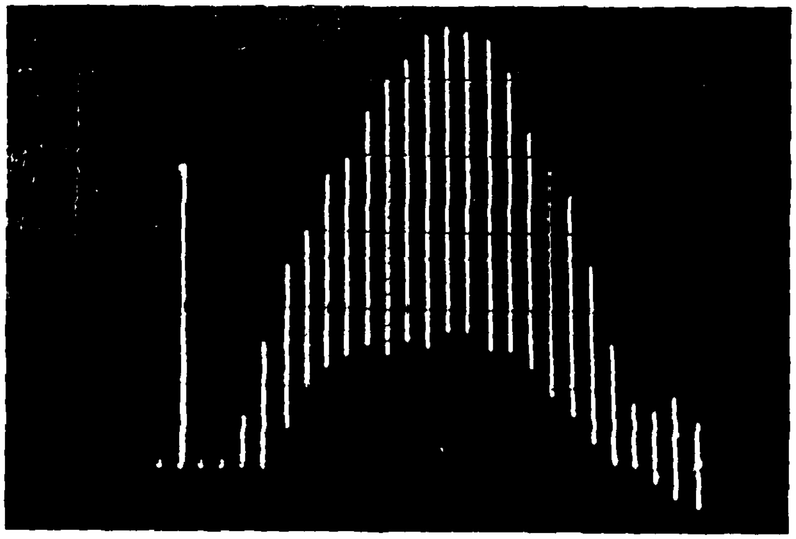
TABLE

| RESULTS FROM A GROUP OF 30 NORMAL SUBJECTS | | | |
|---|---|---|---|
| | | RANGE | MEAN |
| COMMON FEMORAL | FLOW ml/mn | 61-223.5 | 134.13 |
| | DIAMETER mm | 6.8-10 | 7.40 |
| | MEAN VELOCITY cm/s | 4-17 | 8.30 |
| TIBIAL | FLOW ml/mn | 6-42.5 | 18.96 |
| | DIAMETER mm | 2.4-6 | 3.72 |
| | MEAN VELOCITY cm/s | 2-11 | 3.92 |
| DORSAL FOOT | FLOW ml/mn | < 1-19.5 | 7.20 |
| | DIAMETER mm | 1.6-4.4 | 2.62 |
| | MEAN VELOCITY cm/s | < 1-11 | 2.51 |
| COMMON CAROTID | DIAMETER mm | 5-7.4 | 5.80 |
| | FLOW ml/mn | 259-579 | 386 |
| | MEAN VELOCITY cm/s | 20-34 | 26.58 |
| HUMERAL | FLOW ml/mn | 31-91 | 57.11 |
| | DIAMETER mm | 3.4-5 | 4.17 |
| | MEAN VELOCITY cm/s | 3-12 | 7 |

Pulse emission Doppler arterial velocimetry
Results from a group of 30 normal subjects



(a) femoral artery



(b) internal carotid

Figure 6 - Instantaneous velocity profiles obtained from a femoral artery (a) and an internal carotid artery (b).

- For FP as for other patients treated for arterial disease, Doppler *investigation remains* the essential monitoring examination for the assessment of the quality and persistence of the result and provides an objective dossier on which to base discussion of a return to work.

2) Pulsed emission ultra-sonic velocimetry remains at present a research method.

This method would seem to be of particular interest in the realm of aeronautic and space medicine because of its non-invasive nature and the lack of inconvenience caused to the subject. The method can be used to determine arterial flow, flow rate, segmental flow and instantaneous flow rate profiles during aeronautical stress or in passengers during space flights and also to monitor any fluctuations occurring during the various types of stress encountered.

Many fundamental investigations are being carried out at present in order to define measurable parameters of stability of blood flow. Unstable blood flow would appear to be a very important factor in the origin of arterial stenoses (3-5-6-7). It is possible to define an index of flow stability based on the spectrum analysis of the instantaneous velocity profiles (6).

This field of research is all the more rewarding since in the near future vascular ultra-sound will complete the Doppler investigation in an ultra-sonic exploration complex outlined by JAQUET as early as 1970 (4). This ultra sound-angio-Doppleroqraphy is in the process of becoming operational and some experienced workers *have produced excellent* images of longitudinal arterial sections revealing even the slightest parietal abnormality and these are completed by the kinetic information provided by the Doppler effect.

The scope of non-invasive arterial function investigation is in the process of taking the great step forward. It is inevitable that aeronautic and space medicine and research will benefit from this.

## CAPTIONS TO ILLUSTRATIONS

| | |
|---|---|
| Figure 1 : | Principle of Doppler effect determination of blood flow rate |
| Figure 2 : | Doppler flow rate charts obtained from the arteries of the legs |
| Figure 3 : | Stenoses of the two superficial femorals, tight on the right, mild on the left |
| Photograph 1: | Aorto-ilio-femoral arterial angiograph of the patient whose velocimetric study results are shown in figure 3 |
| Figure 4 : | Normal Doppler recordings obtained from the cervical and cephalic arteries |
| Figure 5 : | Obliteration of the left internal carotid upstream from the root of the ophthalmic |
| Photograph 2: | Arterial angiography confirming the obliteration of the internal carotid just after the bifurcation (same patient as that in the flow rate records shown in figure 5). |
| *Figure 6 :* | Instantaneous velocity profiles obtained from a femoral artery (a) and an internal carotid artery (b). |
| Table : | Pulse emission Doppler arterial velocimetry Results from a group of 30 normal subjects. |

BIBLIOGRAPHY

1 - HILTENBRAND Ch., DIDIER A., POIRIER J.M., BONNEL D., ILLE H.
Ce qu'il faut savoir sur l'exploration artérielle par effet Doppler - Dossiers Clin-Midy, 1978.

2 - HILTENBRAND Ch., OTT D., ILLE H., DIDIER A. , LANTRADE Ph.
Vélocimétrie ultrasonore à émission pulsée. Application à la détermination des débits segmentaires chez le sujet normal et chez le sportif.
Comm. à la Séance Commune de la Soc. Med. Ch. des Hôp. et Form. San. des Armées - LYON - 28 Avril 1979 -

3 - ILLE H. , DIDIER A., LANTRADE Ph. , OTT D., et HILTENBRAND Ch.
Apport du Doppler pulsé en pathologie artérielle périphérique.
Med. et Armées, 1980, 8 , 6 , 443-452.

4 - JACQUET M.
Les angéio-échographies A et B et l'angéio-dopplérographie.
Angéiologie, Paris, 1970, 22 , 367-388.

5 - OTT D.
Vélocimétrie ultrasonore Doppler à émission pulsée.
Thèse Med. LYON, 1979.

6 - PERONNEAU P. , HERMENT M., VAYSSE M. , MOUTET J.P.
Vélocimétrie ultrasonore et approche de la stabilité des écoulements du sang .
Coll. INSERM, vol. 78 , sur le systeme artériel, physiologie et investigation clinique - 1978 , p. 95

7 - SANDMANN W., WILDT Ed. , SCHWEINS G et Al.
Mesure des turbulences et valeur fonctionnelle des anastomoses artérielles en chirurgie vasculaire.
Coll INSERM vol. 78 , sur le système artériel, physiologie et investigation clinique - 1978 , p. 183

# CHAPTER 9

## THE CONTRIBUTION OF NUCLEAR MEDICINE TO CARDIOLOGY

by J.F. Gaillard*

Isotopic methods of exploration have developed greatly over the last twenty years and now constitute important complementary cardiological examinations.

In 1948 PRINZMETAL introduced the radiocardiogram by external detection recording of the dilution curve of a radioactive indicator in the cardiac cavities.

In 1964 CARR introduced static scintigraphy, followed by a link-up of the gamma camera to a computer which from the 1970's made possible the development of rapid dynamic investigations and computer-processing of the image obtained.

Recently gamma or positron emission tomography (which is based on the same progress in electronics and algorhythmic reconstruction as tomodensitometry) has provided results in detailed studies of the vascularisation and metabolism of the myocardium.

Isotopic methods provide information which was generally not available previously except by means of invasive radiological explorations using contrast media and recently by ultra-sound.

The non-invasive functional investigation of an organ is the main contribution of nuclear medicine. The possibility of quantifying organ function, of describing it by means of graphs, diagrams and images remains unrivalled as FREEMAN et al (1980) stress.

The contribution of nuclear medicine to the examining expert is important because of the non-invasive nature of most of the methods. We will merely mention any invasive techniques which are to be excluded in the initial investigation of the expert's examination of flying personnel.

## I - TECHNICAL ASPECT OF RADIO ISOTOPIC EXAMINATIONS

Only gamma emitting elements can be used for external detection. Positrons (positive electrons) can be detected only because of the two 511 kev photons which they emit in diametrically opposed directions when they meet a negative electron (annihilation). Positron emitting elements are of interest because the main constituents of living matter have positron emitting isotopes. The major drawback is the short half-life of the compounds which means they can be used only in the immediate vicinity of the cyclotron.

Depending on their physico-chemical properties, radio elements may be used either alone or bound to a vector, the fate of which will be monitored by radiopharmaceutical methods.

### 1. Radioactive substances used

### 1.1 Non-diffusable tracers

#### 1.1.1. Vascular compartment tracers

$Tc^{99m}$ technetium (half-life 6 hours, gamma energy 140 kev) is used to label serum-albumin or, preferably, red blood cells. Using these tracers, it is possible to determine the blood volume, since the radioactivity recorded by the detector is proportional to this volume. Parasitic background noise and tissue attenuation are limiting factors which need correction.

Rather than a determination of the volume itself, changes in volume can be assessed by investigation of radioactivity in function of time. This is used as the basis for calculation of the ejection sections.

#### 1.1.2. Local perfusion indicators

These are essentially albumin microspheres calibrated at 15 to 40 microns and labeled with either $Tc^{99m}$ or by $In^{113m}$.

These microspheres are halted by the capillaries and the local radioactivity level is proportional to the flow.

### 1.2 Diffusable radio tracers

All substances have the same circulatory period and in addition diffusible tracers have a specific distribution corresponding to the radiopharmaceutical involved.

#### 1.2.1 Healthy myocardium labels

##### 1.2.1.1 Potassium analogues

* Médecin Principal, in the Service de Médecine Nucléaire at Val-de-Grâce, France.

Extraction by the myocardial tissue is determined from the coronary flow and from the exchange level between the bloodstream and viable myocardial tissue. The level of exchange depends on the condition of the Na-K-ATPase system, on the diameter of the hydrated ion and the degree of hypoxia (only 30 seconds of hypoxia are required to deplete the myocardial potassium). The clearance of potassium and of its radioactive analogues is lower in the myocardium than in other tissues because of the high intra-cellular concentration which dilutes the active substance.

LEBOWITZ (1973-1975) introduced thallium 201 , the excellent physical and biological properties of which led to the abandonment of other isotopes of potassium, rubidium and cesium. Its 73-hour half-life and the energy of its photons (X of 69 to 83 kev and rarely used gamma of 135 and 167 kev) are not optimal since resolution is impaired by attenuation of the low energy photons and by the diffuse radiation of the higher energy photons.

Immediately after injection, the local binding of thallium is proportional to the blood flow (Strauss, 1975). A few hours later, binding is indicative only of the intra-cellular pool of potassium. Despite these drawbacks it remains the best radio element for the imaging of ischaemic or necrotic zones which are detected because of poor binding.

1.2.1.2. Metabolic substrates of the myocardium

Glucose, fatty acids and amino acids labelled with $C^{11}$, $N^{13}$, $O^{15}$, $F^{18}$, $I^{123}$, can be used to investigate localised myocardial ischaemia, infarction and regional metabolism.

1.2.2. Tracers for the diseased myocardium

The most successful radiopharmaceutical is $Tc^{99m}$ pyrophosphate which is best concentrated within the infarcted myocardium. The mechanism by which it is bound is not completely explained. For the pyrophosphate to be bound a profusion of about 40% of the normal level must remain. This explains the binding around the periphery of the infarction and the optimum timing of the examination (day 2 or 3) before irreversible necrosis sets in and eliminates perfusion.

1.2.3. The inert gases

81 m Krypton (T 1/2 = 13 sec.; 190 kev) produced by a generator is the ideal element for multiple radiocardiographic studies because of its short half life, its energy level which is suitable for gamma cameras and because of the low radiation dose delivered. This radio element is also used to perform isotopic phlebographies.

133 Xenon (T 1/2 = 5.3 d; 79 kev) is more readily available but less suitable than the 127 Xenon (T 1/2 = 36.4 d; 172-203 kev) .

These inert gases are used to determine the regional myocardial blood flow after a wash-out investigation during intra-coronary artery injection. The limiting factors in the use of xenon arise from a small degree of recirculation and the fact that it dissolves in the epicardial fat.

2. Instrumentation

. The single channel probe: X or gamma radiation emitted interacts with a thallium-activated sodium iodide crystal to produce the emission of a bright flash which is detected by a photocathode, amplified and transformed into an electrical signal. The intensity of this electrical signal is proportional to the radiation energy and can be used to eliminate the diffused radiation by spectrometry. There is a revival of interest in this scintillation counter because of the possibility of bedside examination and it is known as the "nuclear stethoscope".

. Gamma cameras: the image is obtained by means of a collimator placed in front of a large flat crystal of sodium iodide and an electronic system localising the scintillation. The image obtained has two dimensions and is simply the projection of the activity present in the field of the gamma camera.

. Data processing: the gamma camera is linked to a micro computer which makes it possible to quantify the images and process them numerically (quantification of the activity in a specific region defined by the operator, preparation of graph, subtraction of the background noise, smoothing and filtering of the image).

. Emission tomography: development of electronic techniques and progress in algorhythmic image reconstruction made it possible to obtain cross-section images. Longitudinal section images are obtained by means of special collimators (multipinhole, Fresnel zone...) and transverse axial sections obtained by means of a revolving head and an image reconstruction algo Rhythm using filtered retroprojection.

Because of the two annihilation photons, positron emitters can provide a cross-section image by means of a special apparatus consisting of a circular or hexagonal arrangement of the detectors and equal-angle detection.

## II - RADIOISOTOPIC EXAMINATIONS, COMMONLY USED IN CARDIOGRAPHY

### 1. Myocardial scintillation scanning

#### 1.1 $Tc^{99m}$ Pyrophosphate: method advanced by BOWTE et al. (1974)

- Protocole : the examination is carried out 60 to 90 minutes after the injection of 15 millicuries of $Tc^{99m}$ pyrophosphate. Images are obtained in the anterior incidence, the left profile and left anterior oblique. If a posterior infarction is being investigated a further image is obtained in the right anterior of the incidence.

- Results: visualisation of the infarcted zone is possible between days 6 and 12, and optimal between days 2 and 3. The sensitivity of the examination varies between 60 to 100% depending on authors. There is only 75% specificity since there are many false positives (cardiomyopathy, valvular calcification and calcification of the chondro-costal cartillage, cardiac contusion, aneurism, electric shock, rib fracture during cardiac massage).

The examination is of both diagnostic and prognostic value, HOLMAN et al. (1978).

There is good correlation between the size and the extent of binding. The mass of infarcted myocardium must exceed three grams to be visible. Following infarction:

- only 5% of patients with a normal scintillation scan will present complications,
- 35% of patients with moderate localised binding will present complications,
- this percentage rises to 88% of patients with considerable diffuse binding.

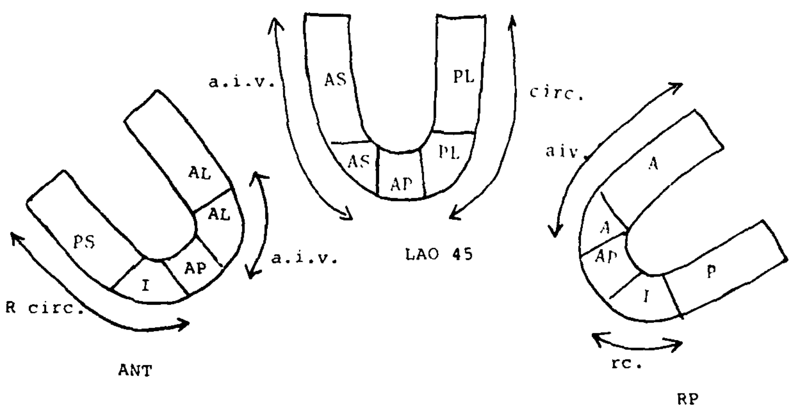
- Value: the diagnostic role is limited to clinical conditions with some element of doubt: infarction of the right ventricle, peri-operational infarction for RIGHETTI et al. (1977), non-specific ECG, contusion, penetrating injury, ... The prognostic importance should not be overlooked and just as the extent of binding is a negative factor, so too is the persistance of this binding 3 to 6 months after the acute incident.

#### 1.2 Static Thallium scintillation scanning

- Protocol : the fasting subject is in the upright position so as to reduce the splanchnic flow and consequently uptake by the viscera. An injection of 2 millicuries of Thallium 201 is administered and ten minutes later at least three incidences are recorded (anterior, left anterior oblique, left lateral) of 500,000 impulses each.

In order to facilitate interpretation, analogic images, digitalist images, smooth images with either systematic (less than 25%) or interpolative subtraction of the background noise may also be carried out.

- Results: In the normal subject the myocardium takes the form of a horseshoe image surrounding the cavity and opening towards the mitral-aortic region and in the left anterior oblique incidence often takes the form of a doughnut (figure 1).




| | | |
|---|---|---|
| ANT | : | *anterior* |
| 45 LAO | : | 45 degree left anterior oblique |
| LP | : | left lateral |
| Circ | : | circumflex |
| a.i.v. | : | anterior interventricular |
| rc | : | right coronary artery |

Figure 1
Myocardial vascularisation territories after LENAERS et al. (1977) and RIGO et al. (1979)

As can be seen on figure 1, a defect can be related to a specific myocardial territory. At rest, visualisation of the right ventricle signifies hypertrophy of the ventricle STEVENS et al (1975).

A localised defective image may take the following forms:

. of a gap: clear amputation (infarction of the myocardium);
. reduced binding : to be significant this should be reduced to less than 80% of the maximal activity and be transmural. This pattern is found in tight stenoses (chronic coronary failure), in rudimentary infarctions which are non-transmural or difficult to situate (posterior) and particularly in the syndrome of threatened myocardial infarction.
. blotchiness : in myocardiopathy whether primitive or not. Obstructive myocardiopathy is easy to recognise from the small size of the cavity and the thickening of the walls but it is very difficult to determine the ischaemic or non-ischaemic nature of a myocardiopathy (defects involving 20 to 40% of the left ventricular perimeter would suggest an ischaemic condition).

According to WACKERS (1976), the sensitivity and specificity for the detection of acute infarction of the myocardium is 88% and accuracy 61%.

- Value: the diagnosis of acute myocardial infarction is possible when the electrocardiogram and case history are not decisive (left bundle branch block, Wolff-Parkinson-White, pacemaker).

The detection of long established infarction is less reliable. One of the limitations of thallium scintigraphic scanning is the impossibility of distinguishing between long-established infarction and recent infarction. About 50% of infarctions result in persistent longterm defects.

In fluctuating angina, scintigraphic scans carried out four hours after the initial examination can establish a differential diagnosis between transient ischaemia and infarction of the myocardium by elimination of the defect. The initial scintigraphic scan should be carried out 6 to 10 hours following the acute clinical crisis.

Identification of high risk patients by anatomical localisation and estimation of the size of the infarction.

Although localisation is satisfactory, the estimation of the size leaves much to be desired and great hopes are entertained for emission tomography which could also identify non-transmural infarctions.

The differential diagnosis between primitive and ischaemic cardiomyopathy is more difficult. MORAND et al (1980) have established the factors suggesting primitive cardiomyopathies:

- an enlarged right ventricle
- diffuse reduced binding not corresponding to a given vascular territory
- contrast between limited reduced binding and considerable ventricular dilatation
- improved binding during medical treatment for cardiac failure.

1.3 Thallium scintillation scan following the exercise test

Protocol : an exercise electrocardiogram is carried out and 2 millicuries of Tl 201 injected at peak exertion, exercise being continued for another 2 minutes. Imaging is carried out as quickly as possible, ideally within 5 minutes of the end of the exercise (See figure 2). Four hours after the exercise test, scintillation scans are carried out using the same incidences in order to obtain differential diagnosis between ischaemia and myocardial infarction by investigation of the redistribution pattern.

Results - exertion increases the contrast by reduction of the background noise (due to increased absorption by the skeletal muscles) and by increased binding by the healthy myocardium.

The most important data provided is the demonstration of a transient ischaemia developped during exercise and its localisation.

In coronary artery disease, the overall sensitivity is between 80 and 92% and the specificity about 90%.

Success varies depending on the artery involved. The method is very satisfactory for the anterior interventricular, fair for the right coronary and poor for the circumflex (sensitivity 50%). If all three arterial trunks are affected the results are poor and the study is purely relative.

The sensitivity and specificity are better than those of the exercise electro cardiogram except in the case of damage to the circumflex, and the exercise ECG and exercise thallium scintigraphic scan are complementary tests.

Value: The exercise scintigraphic scan is useful in:

. demonstrating exercise ischaemia when the ECG is not decisive
. localising the effort ischaemia and so providing an indication for coronary artery angiography with a view to surgery depending on the mono or tri-truncular nature of the condition
. determining whether any new territory is involved in the case of recurring clinical signs from a previous infarction.
. monitoring following installation of a shunt.

Figure 2: Reduced antero-septal binding in 45 LAO, showing exercise ischaemia

1.4 Thallium scintigraphic scanning and pharmacodynamic tests

The isoprenalin (Isuprel) test is similar to the exercise test and is indicated for the investigation of transient ischaemia in patients incapable of carrying out the usual exercise test.

The dipyradamole (Persantine) test is also useful for the detection of ischaemia, ALBRO and GOULD (1978) . This vasodilator increases the coronary flow in a healthy territory by 400% and reduces it in territories affected by stenosis by a phenomenon similar to "theft".

We will merely mention the methylergometrine (Methergin) spasm provocation test.

1.5 Scintigraphic scan using iodine 123 - labelled fatty acids:

This method has yet to be evaluated but it is promising despite the liberation of iodine 123 (following metabolism of heptodecanoic and hexadecanoic acids) resulting in considerable background noise.

It would seem that coronary artery stenosis results in a permanent area of reduced binding at rest with no accompanying redistribution as with thallium.

2. Isotopic ventriculography

2.1 Study at equilibrium, at rest

- Protocol : after labelling of the vascular compartment, the dynamic images, the acquired cardiac cavities, 300 to 500 heart cycles are synchronised with the electro-cardiogram and added to produce a synthetic cyle of about 20 pictures. It is difficult to eliminate the superimposition of the cardiac cavities and the background noise resulting in parasitism. The optimal incidence is the left anterior oblique (about 40 degrees) relative to the axis of the heart) which provides clear septal separation and acceptable separation of the mitro-aortic plane if there is no left atrial hypertrophy.

- Results: before establishing the equilibrium, the first pass studied determines the ejection fraction of the right ventricle, determines its kinetic features and calculates the parameters of overall cardiac function (heart output, circulatory periods).

During the study at equilibrium, parameters of left ventricular function can be determined (ejection fraction, ventricular volume, mean and maximal contraction rate).

The point by point investigation of these parameters provides functional images ( amplitude, phase, regional ejection volumes, regional ejection fractions) of the left ventricle.

Regional kinetic analysis is good in LAO for septal, inferior or apical and postero-lateral territories. Comparison with cardiac catheterisation in RAO 30 reveals less successful investigation of the posterior territory and a better assessment of septal kinetics by LAO isotopic ventriculography.

The overall ejection fractions are well correlated with catheterisation (R = 0.90: 83 subjects in the study by ETHEVENOT et al -1981) and their determination is repeatable.

The determination of the diastolic and systolic left ventricular volumes is satisfactory, GLASS et al (1978).

This technique can be carried out only in good conditions, i.e. in the absence of any disturbance of rhythm (numerous extrasystoles, atrial fibrillation) which hinder the establishment of equilibrium.

- Value : the non-invasive and reliable nature of this method have led to its development.

.Its main contribution is the assessment of patients affected by recent myocardial infarction when it provides prognostic data in cases where contrast angiographic investigation is not possible.

.The early detection of aneurisms and the possibility of repeated investigations make it possible to control the development of infarctions.

.Assessment of the deterioration of ventricular function makes it possible to adjust certain cardiomyotoxic chemotherapies (e.g. adriamycin) by monitoring of patients.

.Determination of the left ventricular ejection fraction and regurgitation fraction confirms diagnosis and the possibility of surgery in mitro-aortic valvulopathies.

## 2.2 Equilibrium ventriculography

### 2.2.1. Exercise test

- Protocol : the same protocol as for the exercise ECG using the ergometric bicycle is used with the patient in the dorsal decubitus position. One determination is carried out at rest and the other at peak exertion.

- Results: in the normal subject, the telediastolic volume increases slightly or remains unchanged whereas the telesystolic volume falls, resulting in increased ejection fraction.

In the coronary patient, the increase in the telesystolic volume is responsible for the fall or lack of change in the ejection fraction.

Furthermore, the dyskinesia induced or aggravated by exercise in the coronary patient serves to localise the condition and is particularly sensitive and specific for the anterior interventricular territory.

- Value: Selection of chronic coronary patients requiring coronary artery angiography with a view to aorto-coronary shunt. Medium and long term follow up monitoring of medical treatment, rehabilitation and surgery.

### 2.2.2. The cold water test and right atrial stimulation

These tests do not provide a very physiological approach and are used only in cases where the exercise test is not possible.

Right atrial stimulation is particularly useful in determining the optimal frequency when tracing a pre-set pacemaker.

### 2.2.3. Pharmacological tests

Nitroglycerin : this test assesses the efficacity of the nitrite drugs which varies from case to case and can be used to select patients with post-infarction aneurism prior to surgery by determining the extent of functional myocardium.

Beta-blockers: ventriculography is carried out before and after beginning this treatment and monitors any deterioration of left ventricle performance.

## 3. Isotopic angiography

- Protocol : the intravenous injection of a radioactive bolus which is followed by computerised recording and 0.5 to 1 second images which visualise the main venous and arterial vessels.

- Results: stenoses of the carotids and sylvians and diagnosis of aortic or iliac aneurisms is possible. Isotopic phlebography is useful in the investigation of the permeability of the inferior vena cava, and of the iliac femoral and internal saphenous veins.

- Value: a non-invasive approach to the diagnosis of aneurisms. In the face of clinical evidence of phlebitis and particularly in cases of chronic thromboses, isotopic phlebography can be used to confirm the permeability of the deep circulation prior to operating for varicose veins.

III - SPECIFIC RADIOISOTOPIC EXAMINATIONS

1. Myocardial tomoscintillation scan

This method is able to determine the intra-mural site of ischaemia or necrosis and provides a quantitative approach to myocardial metabolism ($C^{11}$ palmitate, $F^{18}$ fluoro-deoxy glucose).

2. Cardio-pulmonary shunts

2.1. Left-right shunt heart disease

A dynamic study is carried out of a $Tc^{99m}$ pertechnate radioactive bolus. The quality of the bolus is vital and to improve it a small volume is used and injected into the right external jugular vein rather than into an antecubital vein.

Analysis of graphs of pulmonary transit provides a determination of semi-quantitative indices (ratio of amplitudes and areas) or by means of extrapolation using a gamma function suggested by MALTZ and TREVE (1973), to obtain the ratio of pulmonary and systemic flows well-correlated with oxygen determination. Within the scope of this article the main indications are as an aid in diagnosis of the origin of a murmur and the post operative follow-up of patients to check for any residual shunt.

2.2. Right-left shunt heart disease

Here quantification of the shunt is of less importance since biological criteria are available to determine the cyanosis of these conditions.

Two protocol may be adopted:

- either the intravenous injection of a solution of radioactive gas (xenon 133 or 127). These elements are cleared by the lungs and a right-left shunt is detected from the appearance of radioactivity in the left cardiac cavities of the aorta.

- or by the injection of $Tc^{95m}$ microspheres (less than 50,000) some of which remain in the brain and the kidney if there is a right-left shunt.

3. Radioisotopic investigation of coronary artery perfusion

3.1. Total coronary flow

This determination is carried out using the radiocardiographic method of DE VERNEJOUL and KELLERSHOHN and involves radio-elements of different energy levels, one undergoing passive intramyocardial diffusion (K 42) and the other intraventricular diffusion ($In^{113m}$ sidérophilin).

Since the percentage of diffusible tracer immediately taken up by the myocardium corresponds to the cardiac flow perfusing the heart, the difference between the areas under the left peaks of the two dilution curves indicates the coronary artery fraction of the cardiac flow and the total coronary flow.

3.2 Selective coronary scintigraphic scanning

This is carried out by a selective intra-coronary artery injection of labelled microspheres (10 to 20 microns) and exteriorises a replacement circulation downstream from a coronary artery stenosis.

This is of particular interest prior to installing the shunt during catheterisation during the investigation of the post-stenotic downstream network and after installing the shunt to study revascularisation.

For GAMBINI (1975) this is a valuable method in the assessment of angina with healthy coronary vessels and coronary artery fistulas.

4. Study of the development of thromboses

The KAKKAR test using iodine 125 or 131 labelled fibrinogen and involving serial counts of the legs repeated at intervals is able to detect the formation of a clot and to diagnose the development of phlebitis.

Kinetic study of $Tc^{99m}$ labelled heparin shows a clearance curve with two exponential components, one is very rapid, the other slow. The increased slope of the slow component is an index of the thrombotic development, ESQUERRE et al (1979).

The investigation of the binding of labelled platelets ($In^{111}$) is under assessment.

## IV - THE FUTURE

Positron emission tomography should provide an accurate and quantitative physiopathological investigation of blood flow and metabolism by means of simultaneous determination of mechanical parameters. In the opinion of SCHELBERT (1980), it may be possible to make progress in the early detection of reversible disorders during therapy.

Nuclear magnetic resonance is able to assess myocardial ATP metabolism and provides cross-section images with good resolution. If the procedure time is reduced this method will provide unrivalled kinetic metabolic and morphological studies.

## BIBLIOGRAPHY


ALBRO P.C., GOULD K.L. et al.
Noninvasive assessment of coronary stenoses by myocardial imaging during pharmacologic coronary vasodilatation III. Clinical Trial. Am. J. Cardiol. 42, 751, 1978.

BONTE F.J., PARKEY R.W., GRAHAM K.D. et al.
A new methode for radionuclide imaging of acute myocardial infarction. Radiology 110 : 473, 1974.

ESQUERRE J.P., BONEU B., GUIRAUD R.
Kinetics of technitium lavelled heparin in thromboembolism : prelimanary report. International Jnal of Nucl. Med. and Biol., 6, 215-220, 1979.

ETHEVENOT G., AMOR M., BERTRAND A et al.
Comparaison de la contractibilité globale et locale du ventricule gauche par des méthodes volumétriques, isotopiques et angiographiques. Arc. Mal. Coeur, 12, 1367-1376, 1981.

GAMBINI D.J.
Scintigraphie coronaire sélective. Thèse 1975, Académie de Paris (université René Descartes)

GLASS E.C., JOYE J.A., BERMAN D.S. et al.
Accuracy of noninvasively determined left ventricular volumes by gated radionuclide cineangiography in coronary, valvular and myocardial heart diseases. Am. J. Cardiol. 41, 381, 1978.

HOLMAN B.L., CHISHOLM R.J. BRAUNWALD E.
The pronostic implications of acute myocardial infarct scintigraphy with $^{99m}$Tc pyrophosphate. Circulation 57, 320, 1978.

LEBOWITZ E., GREENE M.W., BRADLEY-MOORE P. et al.
201 Tl for medical use (alestract). J. Nucl. Med. 14, 421-422, 1973.

LEBOWITZ E., GREENE M.W., FAIRCHILD R. et al.
Thallium 201 for medical use I. J. Nucl. Med. 16, 151-155, 1975.

LENAERS A., BLOCK P., VAN THIEL E. et al.
Segmental analysis of Tl 201 stress myocardial scin graphy. J. Nucl. Med. 18, 509, 1977.

LEONARD M., FREEMAN M., DONALD, BLAVFOX
Cardiovascular nuclear medecine Grure et Stratton. Sem. in Nucl. Med. reprint (1981)

MALZ D.L., TREVES S.
Quantitative radionuclide angiocardiography. Determination of Qp/Qs in children. Circulation 47, 1049-1056, 1973.

MORAND Ph., PLANIOL Th., RAYNAUD Ph. et al.
Méthodes isotopiques et cardiomyopathies primitives congestives. Arch. Mal. Coeur, 1, 63-71, 1980.

RIGHETTI et al.
Usefulness of pre and post operative Tc pyrophosphate scans in patients with isthemic and valvular heart disease. Am. J. Cardiol. 39, 43, 1977.

RIGO P., BAYLEY I.K., GRIFFITH S.C. et al.
Value of segmental analysis of stress thallium myocardial imaging for localisation of coronary artery disease. Personal Communication (1979).

SCHELBERT H.R., HENZE E., PHELPS M.E.
Emission tomography of the heart. Sem. in Nucl. Med. 10, 4, 355, 1980.

STEVENS R.M., BAIRD M.G., FUHRMANN C.F. et al.
Detection of right ventricular hypertrophy bu Thallium 201 myocardial perfusion imaging (abstract) Circulation 51, suppl. II, 243, 1975.

STRAUSS H.W., HARRISSON K., LANGAN J.K. et al.
Thallium 201 for myocardial imaging. Relation of Thallium 201 to regional myocardial perfusion. Circulation 51, 641-645, 1975.

WACKERS F.J., SOKOLE E.B., SAMSON G. et al.
Value and limitations of Thallium 201 scintigraphy in N. Engl. J. Med. 295, 1-5, 1976.

# CHAPTER 10
## BALLISTOCARDIOGRAPHY : A NON-INVASIVE METHOD ADVANCING TOWARDS CLINICAL APPLICATIONS

Aristide SCANO, Deputy Director, Postgraduate School of Aerospace Medicine, Rome University.

### 1. INTRODUCTION AND DEFINITION

The ballistocardiographic (BCG) method is a very old one and in about a century of hard and contested life it has had a considerable technical and conceptual development, which has led from the first beds, suspended by means of long ropes, with a mechanical recording to the present air bearing beds with very sensitive acceleration transducers and harmonic analysis of the oscillations recorded. Intended originally to supply non-invasive measurements, easily repeatable, of cardiac output, it turned out to be unsuitable for this purpose owing to the fact that the displacement BCG (as recorded with the early techniques) is sensitive mainly to the properties of the arteries. It was seen later (Starr and Noordergraaf, 1967) that the acceleration BCG is more sensitive to the way in which the ventricles, in particular the left one, eject blood at every beat. That may signify a very important fact, that this method is really a reliable indication of the contractile properties of the myocardium, thus representing one of the most integrative and general techniques of exploration of cardiovascular dynamics.

At present BCG can be defined as a non-invasive experimental method of recording and studying periodic accelerations of the body mass due to the inertia reaction it presents at every ventricular systole. The typical sequence of waves which constitutes the BCG tracing differs quantitatively according to the bodily axis (the ones recorded along the longitudinal axis are generally more ample), according to the state of rest or physical exercise, the age and pathological conditions of the heart and/or the large arterial vessels. We will come back further on to the meaning of the various BCG waves.

### 2. NOTES OF THE EVOLUTION OF THE METHOD

In 1877, J.W. Gordon recorded longitudinal bodily oscillations synchronous with the heart beat of a subject lying on a light bed suspended to the ceiling by means of long ropes. Since the fundamental frequency of the phenomenon is that of the cardiac rhythm and the predominant frequency of the oscillations is about 6 Hz, researchers' efforts were directed to design systems of suspending the bed on which the subject's body rests with natural frequencies less than 0.3 or more than 20 Hz. In this way they passed from suspension with ropes over 5 m long (frequency of pendular oscillation less than 0.2 Hz) to Starr and Rawson's ballistic table (1939), supported by steel springs, with a high natural frequency (but with resonance at about 5 Hz), to Nickerson and Curtis's one (1944) with an ultralow frequency, that is, about 0.2 Hz, to the various device of direct recording (Dock and Taubman, 1949, modified by Arbeit and Lindner, 1959 ; Puddu, 1951 ; Ozaki, 1965), which give recordings altered to a certain extent by parasitic waves and other artifacts, in particular by the so-called "dorsal spring" effect, due to the elasticity of the solft superficial tissues of the dorsal areas of the body which rest on the ballistic table.

The beds that meet the purpose best are air bearing ones (Cunningham and Smiley, 1961), very light and with natural frequencies around 0.2 Hz, one type of which is due to Calderale and Francavilla (1973) of Turin Polytechnic. Talbot (1958) and other scientists also recorded body movements in the three axes of space, with very complex apparatus.

In order to simplify the technique and owing to the fact that there are now available very small and sensitive accelerometric sensors and concave-convex beds (Calderale, Gola and Gugliotta, 1977) which improve the fitting of the subject's body, there is a tendency to return to the use of suspended beds with sufficiently long ropes. With these devices 4 degrees of freedom are obtained and since the useful spectrum of the BCG does not generally exceed 14 Hz, a cutoff frequency around 25 ÷ 30 Hz is recommended.

### 3. PHYSIOLOGICAL FACTORS WHICH DETERMINE THE CHARACTERISTICS OF THE TRACING

The apparent simplicity of the mechanical phenomena which are at the base of oscillations of the ballistocardiogram has often led to oversimplified deductions, which experiments and quantitative analysis have show to be inaccurate. Furthermore, the possibility of obtaining recordings of this phenomenon with the most varied techniques and apparatus (which give different recordings for the same event and can introduce artifacts that are difficult to detect), has produced a number of contradictory and unreliable works. Consequently, the significance of ballistocardiographic waves with reference to the cardiac cycle and the blood flow and the weight of the factors which contribute to their formation are still, at least partly, to be clarified or to be confirmed with certainty, especially through the simultaneous use of other invasive and non-invasive methods.

Actually, in the phenomenon with which we are dealing, multiple factors intervene, which are often mutually dependent, and some of which cannot be directly appraised or measured on the human subject. The main ones are the following :

- the ejection of the blood, especially from the left ventricle (mass and acceleration of the volume of liquid) ;
- velocity of the flow in the aorta and main arteries ;
- size, spatial orientation and elasticity of the main vessels ;
- movements of the cardiac mass because of ventricular systole.

The first factor was demonstrated experimentally on a corpse by Starr, who established that the velocity of ejection of blood from the left ventricle determines the aspect of the set of BCG acceleration waves along the longitudinal axis of the body. The linear relationship between the two variables, admitted to begin with, is now questionable, especially after the research of Goedhard (1979), who obser-

ved in dogs a variation of the transfer function between the blood flow rate in the ascending aorta and the height of the systolic waves of the BCG in different haemodynamic conditions.

By international convention, BCG waves are indicated by letters, beginning with F and ending with N.

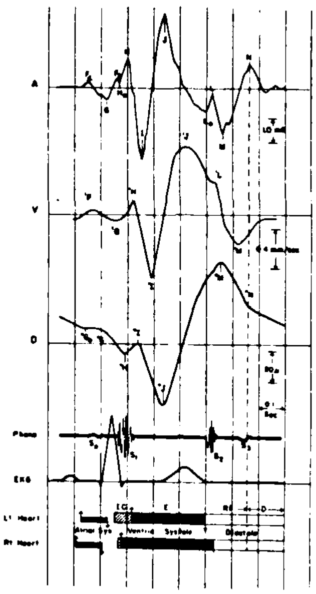



Fig. 1. Relationship among acceleration, velocity and displacement ballistocardiograms to acoustical, electrical and mechanical events in the cardiac cycle (from W.R. Scarborough : Comments on progress in ballistocardiographic research and the current state of the art, F.A.A. Office of Aviation Medicine, Rep. AM 64-12, 1964).

The atrial systole causes small and variable oscillations, such as G, which precede the first positive H wave ; the latter and waves I, J, K (L for some authors) up to the tip of L are related to the systole (isometric contraction, initial aortic valve opening, full ventricular ejection) ; the downward part of the L wave and waves M and N correspond to the beginning of the diastole and to rapid ventricular filling. Interval H - K has a duration practically equal to that of the ventricular systole.

Winer (1979) carried out a careful comparative study of time relationships between direct body, ULF BCG, carotid pulse, phonocardiogram, apexcardiogram, echocardiogram (non-invasive), aortic pulse pressure and left ventricular pressure (invasive). Referring to fig. ...., taken from the above-mentionned work, the pre-ejective notch of the first derivative of carotid pulse corresponds with the middle of apexcardiogram ascending limb and with the H rise. Therefore the H wave would really represent ventricular ejection, which seems to be proved also by the length of the interval between wave Q of ECG and H of BCG, which is 160 msec in the direct body BCG (but in ULF BCG wave H seems outside the ejective phase). Set $S_3$ of the phonocardiogram corresponds to wave K and follows immediately the closing of the aortic valves. According to Goedhard the beginning of the ejection falls between H and I, but it must be remembered that the ULF tracing anticipates the direct body BCG by about 0.04 sec.

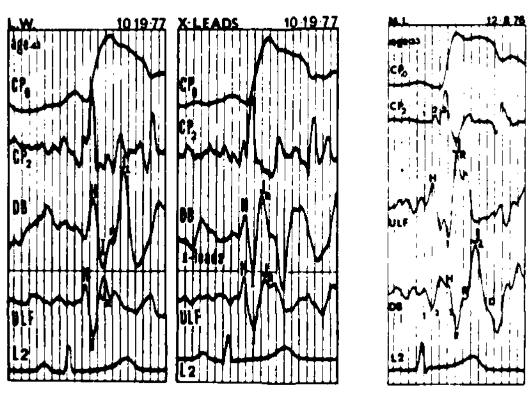


Fig. 2. Left : Crossing the right and left arm leads to DB transforms an approximate mirror reflection of HI to comparable configuration. Note the increased amplitude of J suggesting the effects of body resonance.

Right : The three phases of initial HI ejection are clearly delineated in both DB and Ulf in a young hypotensive female. Note that J configuration remains unaltered (from Winer, see ref. 19).

Most authors do not give much importance to the diastolic waves (descending limb of L, waves M and N) because they are considerably influenced by body resonance phenomena.

The above-mentioned oscillations are found in all acceleration recordings in young and healthy subjects (of lesser amplitude in female subjects) : the movement of blood in the aorta has certainly a part in their genesis (at least from I to K) as was proved by Brown et al. (1949) and by Masini (1952) in subjects with isthmic coarctation of the aorta and by Honig and Tenney (1956) with the ligature of this vessel in dogs : in the first case, the surgical operation normalizes the recording. Other facts that have been proved are the increase, even a considerable one, in the amplitude of systolic waves as the result of physical exercise and of rise in body temperature, and the lesser influence of the right components as compared with the left side of the heart. There is not complete agreement, however, on the waves influenced by exercise (though most researchers indicate J and K) and on the relations among rate of work, variations of the stroke volume and magnitude of changes in the waves themselves. The various attempts made to calculate the volume of systolic ejection from the height and/or area of some waves, usually I and J, are well-know as well as the criticisms made of the most widespread formulae such as that of Nickerson et al. (1947), Tanner (1949) and Starr (1950) : in fact, the oscillations of the tracing represent the integration, instant by instant, of the vectors of the little forces connected with atrial and ventricular contraction with the more important vectors of the acceleration of the blood mass ejected from the ventricles and flowing in large non-parallel vessels, of varying length and elasticity. Furthermore, if it is desired to calculate the work of the heart, the static component, which is certainly the major one at rest, is lacking. These conditions, clearly limitative for anyone trying to obtain from the ballistocardiogram alone the stroke volume and the elasticity of the main arteries, can become advantageous on turning to measurement of the whole of the haemodynamic forces which act during the expulsive phase of ventricular systole. As early as 1953 Masini and Rossi proposed for this purpose the quantitative measurement of the velocity of body movement. The product of this value by the body weight gives the quantity of motion imparted to the body (average 4.3 ± 1.4 kg/m/sec), which seems a good indication of cardiac force, well correlated with physical exercise.

## 4. FIELDS OF APPLICATION OF BALLISTOCARDIOGRAPHY

Some uses with regard to heart surgery have already been mentioned. Let us add that this method supplies useful information on the pumping capacity of the heart and can reveal at an early stage lack of ventricular coordination and irregularity in contractions. It is, therefore, a promising technique for a quantitative evaluation of the heart's functional reserves and for early detection of coronary heart disease and/or myocardial infarction. Obviously, it must be considered in the context of the clinical picture and in the light of other instrumental investigations.

## 5. BALLISTOCARDIOGRAPHIC RESEARCH IN MICROGRAVITY

During the first Spacelab mission, a three-dimensional BCG experiment will be carried out (1ES 028 : P.I. Prof. Aristide Scano, Project Manager Eng. Edoardo Rispoli, Rome University), which we hope will contribute to solving fundamental problems of the method and, consequently, to making its application more useful and reliable. It will permit, in fact, the recording of the accelerations connected with the action of the heart in the three directions of space at rest and after various physical exercises and without any bed or support since the subject is freely levitating in the cabin. This is a unique and ideal condition, which can be obtained only in a laboratory orbiting in space. Other interesting results will be derived from comparison of the tracings obtained on the same subjects on the ground before and after flight and several times during flight itself. That will also make it possible to know if and what changes in BCG take place as a result of prolonged weightlessness and of the return to normal gravity.

REFERENCES


1. BABSKII et al.
The dynamocardiography, Biophysics, 1960, 5, 703.

2. BAYEVSKIJ R.M., YEGOROV A.D., KAZAR'YAN L.A.
A method of seismocardiography, Kardiologya, 1964, 2, 87.

3. BROWN H.R., HOFFMAN M.J., DELALLA V.
Ballistocardiograms in coarctation of the aorta, New Engl. J. Med., 1949, 240, 715.

4. BUSNENGO E.
Valutazione quantitativa del balistocardiogramma dopo lavoro muscolare, Riv. Med. Aeron. Sp., 1960, 23, 385.

5. CALDERALE P.M., FRANCAVILLA A.
Costruzione dei tavoli balistocardiografici. Un nuovo tavolo a due gradi di livertà, 2° Conv. Bioingegneria, Milano, 20-23 novembre 1973.

6. COURNAND A., RANGES H.A., RILEY R.L.
Comparison of results of the normal balistocardiogram and a direct Fick method in measuring the cardiac output, J. Clinical Investig., 1942, 21, 27.

7. CUNNINGHAM D.M., SAUNDERS K.V.
*Ballistocardiography and cardiovascular performance*, 1967, *S. Karger Publ. Basel and New York.*

8. CUNNINGHAM D.M.
Ballistocardiography, Karger Gazette, Oct. 1974, n° 30.

9. DOCK W., TAUBMAN F.
Some technics for recording the ballistocardiogram directly from the body, Am. J. Med., 1949, 7, 751.

10. FOX S.M. et al.
Studies in instantaneous ascending aortic blood velocity in intact man relative to the acceleration ballistocardiogram, Meet. Ballistocardiographic Res. Soc., April 29, 1961, Atlantic City.

11. FRY D.L.
The measurement of pulsatile blood flow by the computed pressure gradient technique, I.R.E. Transactions on Med. Electronics, 1959, ME-6, 259.

12. GOLDMAN D.E., VON GIERKE H.E.
The effects of shock and vibration on man, Lecture and Rev. Series, n° 60-3, NMRI, Bethesda, Md., Jan. 1960.

13. GORDON J.W.
On certain molar movement of the human body produced by the circulation of blood, J. Anat. & Physiol. 1877, 11, 533.

14. GRAZIANI G.
Le balistocardiogramme au cours du travail musculaire, Acta Cardiologica, 1956, 11, 319.

15. HENDERSON Y.
The mass-movements of the circulation as shown by a recoil curve, Am. J. Physiol. 1905, 14, 277.

16. HIXSON W.C., BEISCHER D.E.
Biotelemetry of the triaxial balistocardiogram and electrocardiogram in a weightless environment, Nav. Aerosp. Med. Inst. Monograph N° 10, August 1964, Pensacola.

17. HOLLIS W.J.
Systolic velocity I J stroke values of normal males from an ultralow frequency pendulum ballistocardiograph, J. Appl. Physiol., 1959, 14, 865.

18. HONIG C.R., TENNEY S.M.
Relationship between the ballistocardiogram, cardiac movement and blood flow, Amer. Hearth J., 1956, 52, 167

19. JUZNIC G. (Editor)
Noninvasive Access to Cardiovascular Dynamics : Experimental an Applied. Biblthca cardiol., n° 37, 1979, Karger Basel.

20. JACKSON D.H., MOLINA E.
A computer method for studying the postexercise ballistocardiogram, Am. Hearth J., 1967, 74, 513.

21. JACKSON D.H., OBERMAN A., MITCHELL R.E., GRAYBIEL A.
Factors contributing to the ballistocardiographic waveform in healthy middle-aged men, Amer. J. Cardiol., 1967, 20, 531.

22. JOSENHANS W.T., WANG C.S.
A modified ballistic method for measuring axial mass displacement caused by breathing, J. Appl. Physiol., 1970, 5, 679.

23. KEEFE J.K., RAUTERKUS L.T., WOLK M.H., BRAND D.H., LEVINE H.J.
Electrostatic ballistogram : analysis of electrical fields about the human body. J. Appl. Physiol., 1970, 28, 89.

24. LEQUILE J.
Le débit cardiaque, 1940, Masson, Paris.

25. LIEBAU G.
Die Bedeutung der Trägheitskräfte für die Dynamik des Blutkreislaufs, Z. Kreislaufforschg., 1957, 46, 426.

26. MANLEY M.T., PATON W., MONTGOMERY J.
Lightweight carbon fibre structures - their pratical use in ballistocardiography, Composites., 1973, 79.

27. MASINI V., MARTINI G., ROSSI P.
Progetto di un balistocardiografo, Riforma Med., 1952, 66, 313.

28. MASINI V., ROSSI P.
Morfologia del balistocardiogramma nei soggetti non cardiopatici di oltre 40 anni, Il Policlinico, sez. prat., 1952, 59, 1623.

29. MASINI V., ROSSI P., MARTINI G.
Ricerche balistocardiografiche : il balistocardiogramma nei soggetti normali, Riforma Med., 1952, 66, 496.

30. MASINI V., BUSNENGO E., MARTINI G.
Aspetti funzionali del cuore rispetto all'età in soggetti non cardiopatici. Rilievi balistocardiografici. Atti V Congr. Med. Aeron., 20-23 sett. 1953, Napoli.

31. MASINI V., ROSSI P.
Studies of quantitative ballistocardiography : the velocity of body displacement in patients with heart disease, Circulation, 1953, 8, 381.

32. MASINI V., ROSSI P.
A new index for quantitative ballistocardiography : the velocity of body displacement, Circulation, 1953, 8, 276.

33. MASINI V., BUSNENGO E., MARTINI G.
Il comportamento del balistocardiogramma in anossia, Riv. Med. Aeron., 1953, 16, 15.

34. MASINI V., VENERANDO A., BUSNENGO E., MARTINI G.
Il balistocardiogramma da sforzo nel soggetto normale e nello sportivo, Rev. suisse Méd. Sport, 1954, 2, 83.

35. MOLOMUT A.C., SHANNON C., ALLEN A.C.
Effect of breathing on circulation at high altitude as measured by the ballistocardiograph, J. Aviat. Med., 1946, 8, 357.

36. MONTOYE H.J., COLLINGS W.D., STAUFFER G.C.
Effects of conditining on the ballistocardiogram of college basketball players, J. Appl.Physiol., 1960, 15, 449.

37. MOSS A.J., BRADLEY B.E.
Ballistocardiographic response to hyperthermia, J. Appl. Physiol., 1960, 15, 445.

38. NICKERSON J.L., CURTIS H.J.
The design of the ballistocardiograph, Am. J. Physiol., 1944, 142, 1.

39. OZAKI T. et al.
On the relationships between minor tremor and ballistocardiogram in man, Acta Med. Nagasaki, 1965, 9, 120.

40. OZAKI T., SASAKI S., IGARASHI K.
Ballistocardiography simplified by recording microvibration of the skin surface of the head, Tohoku J. Exp. Med., 1970, 102, 99.

41. PUDDU V.
Una semplice tecnica per eseguire balistocardiogrammi, Cuore e Circol., 1951, 35, 334.

42. RAPPAPORT M.B.
Displacement, velocity and acceleration ballistocardiograms as registered with an undamped bed of ultra-low natural frequency. I. Theory and dynamic considerations. II. Instrumental considerations, Am. Heart J., 1956, 52, 483 & 643.

43. SCARBOROUGH W.R.
Comments on progress in ballistocardiographic research and the current state of the art, Office of Aviat. Med., F.A.A., Rep. AM64-12, 1964, Washington.

44. SCARBOROUGH W.R.
Ballistocardiography : a bibliography, NASA SP-7021 (FAA AM65-15), 1965 (about 1500 references).

45. STARR J. et al.
Studies on the estimate of cardiac output in man of the abnormalities in cardiac function from the heart's recoil and blood's impact : the Ballistocardiogram, Am. J. Physiol., 1939, 127, 1.

46. STARR J. et al.
Standardization of the ballistocardiogram by simulation of the heart's function at necropsy : with a clinical method for the estimation of cardiac strength and normal standards for it, Circulation, 1950, 1, 1073.

47. STARR J., NOORDERGRAAF A.
Ballistocardiography in cardiovascular research, 1967, North Holland Publ. Co., Amsterdam.

48. TALBOT S.A.
Physical principles of vector ballistocardiographic measurement, ARDC Techn. Rep. 58-72, June 1958.

49. TANNER J.M.
The construction of the normal standards for cardiac output in man, J. Clin. Investig. 1949, 28, 567.

50. VADOT L.
Mécanique du coeur et des artères, 1967, L'exp. sci. franç., Paris.

51. WITTERN W.W.
Ballistocardiography with elimination of influence of vibration properties of body, Amer. Heart J., 1953, 46, 705.

# CHAPTER 11

## USE OF CHANGES IN ELECTRICAL IMPEDANCE IN CARDIOLOGY

by J. Colin*

### 1 - INTRODUCTION

The investigation of variations of electrical impedance is of particular value amongst the non-invasive methods used in physiological and clinical study of heart function because of the absence of risk, ease of the procedure and the possibility of repeating determinations or carrying out continuous determinations over long periods.

The bases of the method of determining electrical impedance of a body segment were laid some time ago, particularly by ATZLER (1), BARNETT (3), HORTON (18) and NYBOER (28). More recently, GOUGEROT AND MONZEIN (14) have carried out a very thorough experimental and theoretical clinical study.

### 2 - PRINCIPLE OF THE METHOD

The method used for the investigation of segmental or whole body changes in electrical impedance is based on Ohm's law. According to this law, the potential difference V determined at the ends of an electrical conductor of resistance R, to a direct current I, is given by the following equation: $V = R.I$ If I is constant, then changes in R can be followed by determination of V.

In a body segment, these phenomena are more complex than in a uniform electrical conductor. When an electrical current is passed through this segment by means of surface electrodes, which are known as injection electrodes, lines of current are set up . These lines extend from one injection electrode to the other, but their pathway is complex since it depends on the conducting elements making up the body tissues.

If two other electrodes, known as detector electrodes, are placed between these injection electrodes, it is possible to measure the potential difference between the two equipotential surfaces of these electrodes. These equipotential surfaces are perpendicular to the lines of current and they too have a complex form.

If the injected current is kept constant, any change in the resistance of the conducting elements between the equipotential surfaces is accompanied by a change in the potential difference recorded. Such changes of resistance may be due to several causes:

- changed blood or organic liquid content in the body section;
- changed shape or position of any organs between the equipotential surfaces;
- changed level of air which may be contained in the segment.

The following features may be observed: slow changes in resistance due to changes of volume of the venous and extra-cellular sectors, rapid changes due to pulsation of the arteries and capillaries, or of the heart cycle, or changes synchronised with the breathing due to changes in the volume of air contained in the lungs.

The tissues of the body, and especially cutaneous tissues, are not pure resistances but impedances. This is why it is necessary to use an alternating injection current with a frequency such that the de-phasing due to the capacity of the tissues is kept as low as possible.

By using a constant injection current with a correct frequency, recording of the changes in potential difference between the detector electrodes provides an indirect recording of the changes in volume of the conducting elements of the body placed between these electrodes. This explains the name of electrical impedance plethysmography often given to this method. Depending on the siting of the electrodes on the body it is possible to study the following features:

- pulmonary ventilation: electrical impedance pneumography
- the volume of extracellular or intracellular fluids or the total water within the body : total electrical impedance
- cerebral circulation: cerebral electrical impedance plethysmography
- circulation within the limbs : peripheral electrical impedance plethysmography
- the presence and amount of thoracic fluid: thoracic plethysmography used to detect haemorrhage or pleural effusion for example
- heart function: thoracic, aortic or cardiac plethysmography.

However, in all these cases, it is important to remember that all the organs lying between the equipotential surfaces tested contribute to any changes in impedance detected. In other words, the determination of changes of electrical impedance is an overall method. However, all the organs situated between the equipotential surfaces do not have the same effect. Those crossed by the shortest lines of current have the greatest effect for a given change of resistance. Thus it is possible by specific arrangement of the electrodes to concentrate on the effect of changes in volume of a given organ but it is not possible to avoid some effect from changes in volume of other organs. It is also necessary in many cases to take into account the movement of the organs (which move from one line of current to another) and to a lesser extent changes in shape. For all these reasons, the simple formulae derived from Ohm's law for the calculation of a change in volume can only be used with prudence.

* Centre de Recherches du Service de Santé des Armées - 1 bis, rue Lieutenant R. Batany 92140 Clamart, France.

3 - INSTRUMENTS

Two types of instrument are used to record changes in electrical impedance: two-electrode instruments and four-electrode instruments.

Two-electrode instruments
The same electrodes are used both to inject the current and to detect potential differences. The main drawback of this type of instrument is its greater sensitivity to changes in cutaneous impedance.

Four-electrode instruments
These are more numerous and they measure the impedance between two equipotential surfaces of the electric field set up by the applied current. This current is usually a sinus-wave current with a frequency of between 100 and 150 KHz and of low intensity of the order of 5 m A. The current is an imposed current, i.e. with constant intensity and is usually obtained by the use of high resistances placed in series. Changes in cutaneous impedance then become negligible as compared with the total impedance of the system and the current can be considered to be constant.

Most commercially available instruments are able to detect and record the following:

- the baseline impedance $Z_0$ existing between the two equipotential surfaces through the recording electrodes,
- the rapid changes of impedance $\Delta Z$ around the baseline impedance
- the first derivative of dZ/dt of these rapid changes in impedance
- the electrocardiogram recorded from the injection electrodes.

These instruments often include a phonographic recording channel. The electrodes used are often strip electrodes placed around a limb or a thorax. More rarely small electrodes are used of the same type as used in electrocardiography or electroencephalography.

4 - THORACIC PLETHYSMOGRAPHY

This method, which has been studied particularly by KUBICEK (22) uses strip electrodes about 6 mm wide and placed around the neck, thorax and abdomen. The injection electrodes are placed in a distal position relative to the detection electrodes. The upper injection electrode is placed around the neck at least 3 cm above the upper detecting electrode which is placed around the base of the neck. The lower detector electrode passes around the lower part of the sternum, about 10 cm above the lower injection electrode which is placed around the abdomen.

This electrode set up is used for the determination of the following:
- systolic time intervals
- cardiac output
- thoracic fluid.

4.1 Determination of systolic time intervals

Since the $\Delta$ Z recording is sensitive to respiration, a recording of the first derivative of the changes in impedance is to be preferred. The dZ/dt recording has some characteristic points (figure 1).:
- point A - This point lies between the end of the electrocardiographic P wave and the beginning of the QRS complex . It occurs at the same time as the fourth heart sound where this can be detected.
- point B - This point occurs at the same time or within two seconds following the maximal deflexion of the first heart sound.
- the crossing of the zero line by dZ/dT - This point is equivalent to the onset of left ventricular ejection
- point X - This point coincides with the aortic component of the second heart sound and the closing of the aortic semilunars.
- point Y - This point occurs at the same time as the pulmonary component of the second heart sound
- point Z - This point occurs at the same time as the third heart sound if this sound can be recorded
- point O - This point corresponds to the opening of the mitral valve as detected by the apex cardiogram

The chronology of these points relative to the phonocardiogram, electrocardiogram and apex cardiogram has been studied by LABABID (23). These points can be used to determine the pre-ejection period Q interval - cross over of dZ/dt and the zero line: PEP) and the left ventricular ejection time (the time between the dZ/dt zero line cross over and point X: LVET).

Point X is unfortunately often missing and this necessitates simultaneous recording of the phonocardiogram. By determining the time between the passage of dZ/dt to zero andthe first high frequency vibration of the second heart sound the LVET can be determined. RASMUSSIN et al (29) found excellent correlation in the dog between the LVET determined in this manner and that obtained from the aortic pressure recording (r = 0.986). HILL and MERRIFIELD (17) carrying out the same procedure in man using the phonocardiogram and comparing the results with those obtained from the carotid pulse determination, found that the LVET determined from the plethysmograph was generally 0.88% shorter and showed excellent correlation with the LVET determined from the carotid pulse (r = 0.95). The electrical impedance thoracic plethysmograph can therefore be used to determine the systolic time intervals and this method has been used particularly during physical exercise (GOLLAN et al 13., VAN FRAECHEM et al 34).

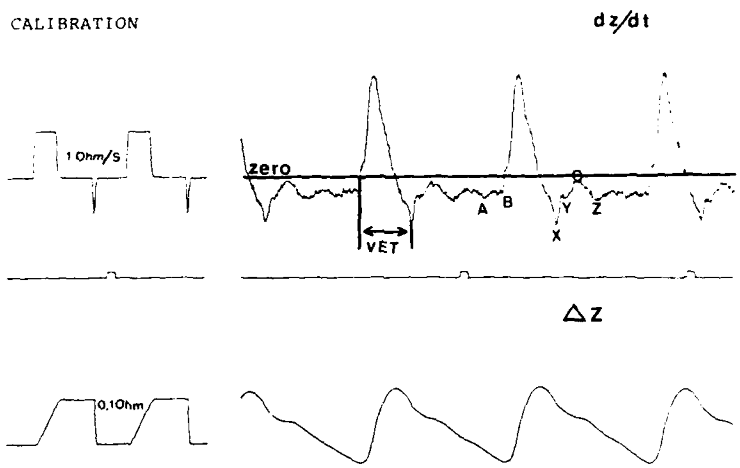



Figure 1 - Example of thoracic electrical impedance plethysmography. Below, the change in impedance, $\Delta Z$, above the derivation of the change in impedance dZ/dt.
The various points shown on the recording are as follows:
A corresponds to the fourth sound
B corresponds to the first sound
X corresponds to the second aortic sound
Y corresponds to the second pulmonary sound
O corresponds to the mitral opening
Z corresponds to the third sound

## 4.2 Evaluation of the cardiac output

During heart cycle, the speed of change of the carotid impedance reaches a maximum value (dZ/dt max.) during ventricular ejection. A formula derived from Ohm's law has been suggested by KUBICEK (23) in order to evaluate the systolic volume SV:

$$SV = \rho\left(\frac{L}{Z_o}\right)^2 \cdot (dZ/dt\ max). \ LVET$$

where:

L is the distance between the two detector electrodes, in cm
$Z_o$ is the base line impedance between the two detector electrodes, in Ohms
dZ/dt max is the maximum value of dZ/dt found during ventricular ejection in ohms per second
LVET is the left ventricular ejection time, in seconds, measured as described above
$\rho$ is the resistivity of the blood at the frequency used by the instrument
For a frequency of 100 KHz the mean value of $\rho$ is 150 ohms/cm. A more accurate value can be calculated from the haematocrit (GEDDES and SADLER - 12)

The cardiac output can easily be obtained by multiplying the systolic volume by the heart rate.

Comparison of the systolic volume and the cardiac output obtained in this way with those determined by traditional methods (the Fick method, dye dilution, thermo-dilution, radio-isotopes) has led to discordant findings. Some authors have obtained satisfactory correlation: DENNISTON et al. (10), HILL and MERRIFIELD (17), NAGGAR et al (27), RASMUSSEN et al (29-30); others obtained poor correlation: BOER et al (5), KINNEN (21), KUBICEK et al (22), LABABIDI et al (23), SIEGEL et al (32), SMITH et al (33); and others again very poor correlation: BAKER et al (2), ENGHOFF and LOVHEIM (11), HARLEY and GRENNFIELD (15), JUDY et al (19), KEIM et al (20), SECHER et al (31). From the study of these different findings it is however possible to draw some general conclusions:

- The method is suitable for use only in patients free from severe valve disease or intracardiac shunts
- The method gives better results in the healtny subject but the scatter of results is too great to give any reliable absolute value
- Most authors think that there is a satisfactory correlation between changes in volume determined by this method and by reference methods.

The interest of the method lies in the possibility it affords of following changes in systolic volume, systole by systole and the fact that it can be used continuously and during physical effort (VANRAECHER (34), DENNISTON et al (10), GOLLAN et al. (13)) during a change in position (BEVEGARD et al (4), HILL et al (17), SMITH et al. (33) or during an anaesthesia (HILL and LOWE (14), McKENSIE et al.(25) .

4.3 Evaluation of myocardial contractility

The ratio PEP/LVET, the inverse of the square of the pre-ejection period ($1/PEP^2$), the HEATHER index (ratio of the maximum value of dZ/dt to the interval of time separating the R-wave from the dZ/dt maximum) are indices of myocardial contractility which can be used with thoracic plethysmography.

## 5. AORTIC PLETHYSMOGRAPHY

### 5.1 Thoracic electrodes

In order to maximise effects due to the aorta and minimise the respiratory oscillations of the impedance variation recording, DEMANGE et al (9) have suggested placing the detector electrodes on the anterior surface of the thorax, opposite the ascending aorta, about 3 cm apart. These are 10 cm long and 1 cm wide strip electrodes. The injection electrodes are identical in form and one is placed on the anterior surface of the neck and the other at the base of the thorax. The recording obtained (2) is not a pure aortic recording but a composite record with analogies with the thoracic plethysmogram.

### 5.2 Systolic time determinations

The "aortic" plethysmogram makes it possible to determine the pre-ejection period, the time between the Q-wave of the electrocardiogram of the foot of the plethysmogram and the left ventricular ejection time, the time separating the foot of the "aortic" plethysmogram notch.

Comparison of the results obtained by this method with those obtained from the carotid pulse and the phonocardiogram recorded simultaneously in 91 healthy subjects, (COLIN and CARRE (6), (7) gave the following results:

The left ventricular ejection time obtained by plethysmography ($LVET_{plet}$) is 57 ms longer than that obtained from the carotid pulse ($LVET_{carot.}$) and is well correlated with this:

$$LVET_{carot} = 119 + 0.47\ LVET_{plet} \quad \text{where } r = 0.75$$

A better result is obtained by using $S_2$ instead of the plethysmogram notch to indicate the end of the left ventricular ejection: the $LVET_{plet}$ is then 33 ms shorter than the $LVET_{carot.}$ and the correlation is improved:

$$LVET_{carot.} = 91 + 0.76\ LVET_{plet.} \quad \text{where } r = 0.80$$

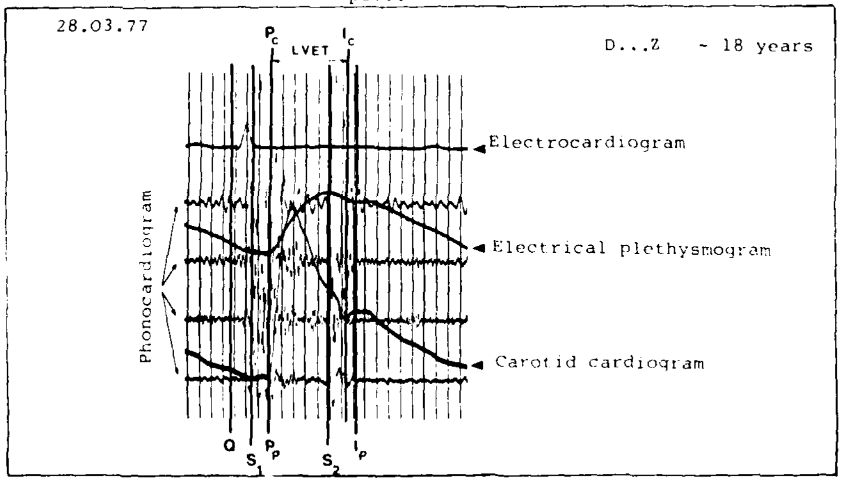



Figure 2: Example of "aortic" electrical impedance plethysmograph carried out simultaneously with the carotid cardiogram, the electrocardiogram and the phonocardiogram.

Q - electrocardiographic Q-wave
$S_1$ - first high frequency component of the first heart sound
$S_2$ - first high frequency component of the second heart sound
$P_c$ - foot of the carotid cardiogram (beginning of the rapid rise in the recording)
$I_c$ - catacrotic notch of the carotid cardiogram
$P_p$, $I_p$ - foot and notch of the "aortic" plethysmogram.

This finding shows that the notch on the plethysmographic recording corresponds to the closing of the pulmonary semilunars and that the so-called aortic record is in fact composite .

5.3 Evaluation of the cardiac output

Comparison of the cardiac output values obtained by the dilution method and by aortic plethysmography using KUBICEK's formula in 120 subjects, has demonstrated that there is only poor correlation (r = 0.58) between the two methods and this shows that "aortic" plethysmographic evaluation of the cardiac output does not provide better results than thoracic plethysmography (COLIN and CARRE (6)) despite the encouraging results that were obtained initially by DEMANGE et al. (9).

5.4 Oesophageal electrodes

Recently MITCHELL and NEWBOWER (26) used four electrodes placed on an oesophageal probe. In the dog they simultaneously recorded the aortic pressure and checked that the method does provide an accurate determination of the pre-ejection period and the left ventricular ejection time. They also found that the changes in electrical impedance recorded were due more to the movements of the aorta than to changes in its volume and that this method cannot be used to evaluate the cardiac output.

## 6 - CARDIAC PLETHYSMOGRAPHY

Because of the limitations of the thoracic and aortic plethysmography, COLIN and CARRE (7) experimented with an arrangement of the electrodes favouring detection of the effects of changes of volume and position of the heart on electrical impedance and providing a correct determination of the systolic time intervals without the drawback of the usual method of carotid pulse recording.

The electrode arrangement which gave the most satisfactory results was as follows:

- the current injection electrodes are placed one at the base of the neck, beneath the suprasternal notch, and the other on the left side of the abdomen about 8 cm below the tip of the heart.
- the detection electrodes are placed in the precordial region and on the left border of the sternum. The upper electrode is placed in the third or fourth intercostal space on a level with the nipple. The lower electrode is placed about 5 cm below, at the level of the tip of the heart.

The electrodes used are normal electrocardiographic electrodes.

Detection electrodes are used to determine the potential difference between the two surfaces on which they are placed. Between these surfaces lie the ventricles, the atria, the aorta, the pulmonary artery, the vena cava, and lung tissue. But because of their proximity to the recording electrodes, the ventricles have a predominating effect on changes in impedance. Because of this there is an increase in the electrical impedance when the heart empties during ventricular ejection and a reduction of impedance when it fills during diastole. A certain number of other phenomena are superimposed over this basic pattern. These are probably due mainly to the following factors:

- the increase in volume of the root of the aorta, and of the pulmonary artery during ventricular ejection; these are near to the upper detector electrodes and so influence changes in electrical impedance.
- to movements of the heart during the cardiac cycle, to respiratory movements and changes in body position. The electrical impedance increases when the heart moves away from the thoracic cage and vice versa.
- to a lesser degree, to changes in the shape of the heart during the heart cycle.

An initial study carried out by COLIN et al (7), consisted in comparing the recording of changes in cardiac electrical impedance obtained from 100 healthy subjects with the simultaneously recorded electrocardiographic, phonocardiographic and carotid pulse recordings (figure 3).

The cardiac plethysmogram presents four characteristic features:

1°) An increase in intervening impedance shortly after the beginning of the first heart sound ($S_1$)

2°) A reduction of impedance or a sudden slowing of the increase in impedance usually occurring 33 ms after $S_1$ and 30 ms before the foot of the carotidogram.

3°) A sudden change in the rate of increase of impedance, on average occurring 6 ms before the first high frequency vibration of the second heart sound ($S_2$).

4°) A reversal of the recording indicating a reduction of impedance.

The third feature corresponds to the closing of the aortic semilunars (AC) and hence to the end of left ventricular ejection. If it is supposed that the second feature corresponds to the increase of volume of the root of the aorta near the upper detector electrode, it should be possible to determine the following:

- the Q-2 time interval, which is equivalent to the pre-ejection period $PEP_{plet}$
- the 2-3 time interval, which would be the left ventricular ejection time $LVET_{plet}$.

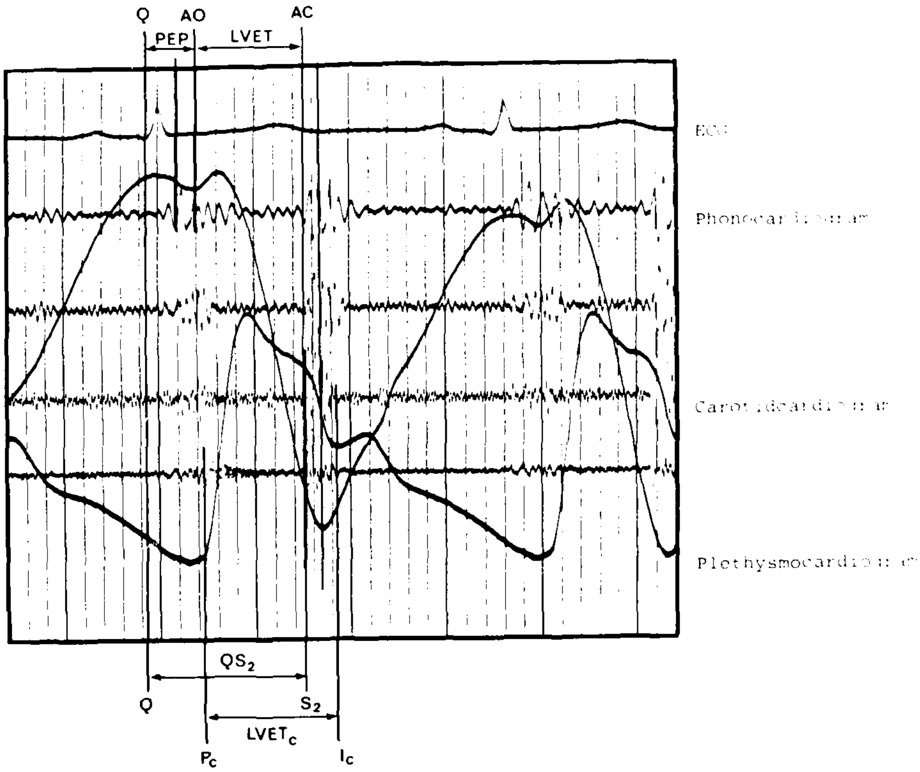



Figure 3. Example of the simultaneous recording of the electrocardiogram, the carotid cardiogram and the plethysmogram showing the reference points selected to determine the left systolic time intervals (the pre-ejection period LPEP and ejection period LVET).
AO : Aortic opening
AC : Aortic closing
$S_2$ : First high frequency component of the second sound
Pc and Ic : Foot and notch of the carotid cardiogram.

Comparison with the usual carotid pulse determination method gave the following correlations:

$$LVET_{(plet)} = 0.90\ LVET_{(carot.)} + 15.6 \text{ where } r = 0.81$$

$$PEP_{(plet)} = 0.55\ PEP_{(carot.)} + 51.5 \text{ where } r = 0.65$$

The fourth reference point occurs on average 30 ms after $S_2$ and it has not been possible to relate it to any precise cardiac event.

These results confirmed the hypothesis that point 2 corresponds to the opening of the aortic semilunars (AO), and seemed to be sufficiently significant to continue with the study, but this time using the first derivative of the change of electrical impedance which improves the accuracy of deciphering the recording and has the advantage of low sensitivity to respiration.

The recording of the impedance derivative (figure 4) presents five characteristic features, the last four of which correspond to the four reference points studied above.

An initial series of simultaneous recordings from the cardiac plethysmogram, the carotid pulse cardiogram, the phonocardiogram and the electrocardiogram taken from 50 healthy subjects confirmed the previous findings:

- Point 3 usually occurs 1 ms after the aortic components of the second heart sound and can be considered as a satisfactory indication of the time of aortic semilunar closing.

- The correlations between the time intervals determined by the two methods were also satisfactory:

$$LVET_{plet} = 11 + 0.97\ LVET_{carot.} \quad \text{where } r = 0.95$$

$$PEP_{plet} = 30 + 0.66\ PEP_{carot.} \quad \text{where } r = 0.83$$

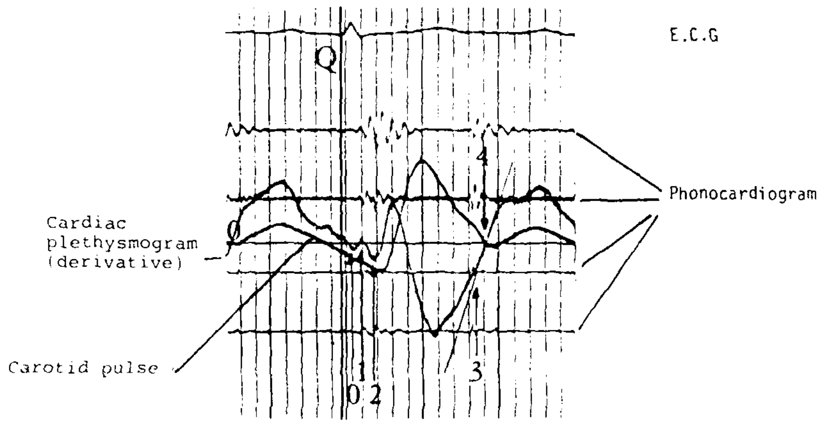



Figure 4 - Simultaneous recording of the derivative of the change in cardiac electrical impedance, the carotid pulse, the electrocardiogram and the phonocardiogram

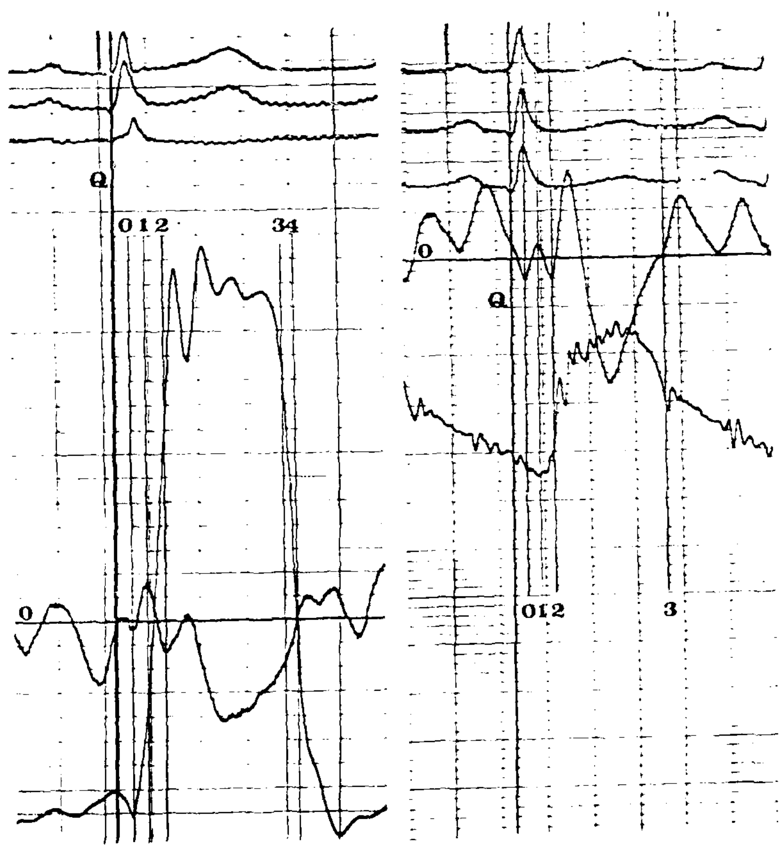



Figure 5 - Examples of simultaneous recording of the derivative of the change in cardiac electrical impedance and:

A - left ventricular pressure
B - the pressure at the root of the aorta.

A final study involving the simultaneous recording of pressure by means of a right and left catheter and of the cardiac plethysmogram in 32 subjects has confirmed these conclusipns and further defined the significance of these reference points (figure 5).

- Point 0 corresponds to the beginning of the left mechanical systole
- Point 2 corresponds to the onset of left ventricular ejection (opening of the aortic semilunars)
- Point 3 corresponds to the end of left ventricular ejection (closing of the aortic semilunars)

Cardiac electrical plethysmography can therefore provide a good evaluation of the left systolic time intervals. The method uses only the usual ECG electrodes which are easy to install and do not inconvenience the subject. These electrodes make it possible to record simultaneously the ECG and the first derivative of the change in electrical impedance during relatively long periods of time which may be up to several days. It is not necessary to submit the subjects to apnoea and the method, which does not require the phonocardiogram is not affected by noise.

## BIBLIOGRAPHY

1 - ATZLER E., LEHMAN G.
Uber ein neues verfahren zur dastellung der herztaätigkeit (dielecktographie).
Arbeitsphysiologie 1932, 6, 636 - 680.

2 - BAKER L.E., JUDY W.V., GEDDES L.E., LANGLEY F.M., HILL D.W.
The measurement of cardiac output by means of electrical impedance.
Cardiov. Res. Cent. Bull. 1971, 9 (4), 135 - 145.

3 - BARNETT A.
The phase angle of normal skin.
J. Physiol. 1938, 93, 349

4 - BEVEGARD S., HOLMGREN K., JONSSON B.
The effect of body position on the circulation at rest and during exercise, with special reference to the influence of stroke volume.
Acta Physiol. Scand. 1960, 49, 279 - 298.

5 - BOER P., ROOS J.C., GEYSKES G.G., DORHOUTMEES E.J.
Measurement of cardiac output by impedance cardiography under various conditions.
Am. J. physiol. 1979, 237 (4), H 441 - H 496.

6 - COLIN J., CARRE R., AMORETTI R.
Impedance électrique et mécanographie, méthodes d'investigation cardiovasculaire en médecine aéronautique.
Med. Aéro. et Spat. 1978, 65, 13 - 20

7 - COLIN J., CARRE R., AMORETTI R.
La mesure des intervalles de temps systoliques par une nouvelle méthode externe.
Médecine et Armées 1978, 9 (6), 775 - 782.

8 - COLIN J., TIMBAL J.
Measurement of systolic time intervals by electrical plethysmography : validation with invasive and non invasive methods.
Aviat. Space Environ. Med.

9 - DEMANGE J., PERNOD J., HAGUENAUER G., COLIN J.
Mesure du débit cardiaque par plethysmographie électrique thoracique localisée.
Nouvelle presse médicale 1972, 45 (1), 3065 - 3067.

10- DENNISTON J.C., MAHER J.T., REEVES J.T., CRUZ J.C., CYMERMAN A., GROVER R.F.
Measurement of cardiac output by electrical impedance at rest and during exercise.
J. Appl. Physiol. 1976, 40 (1), 91 - 95

11- ENGHOFF E., LOVHEIM O.
A comparison between the transthoracic electrical impedance method and the direct Fick and the dye dilution methods for cardiac output measurements in man.
Scand. J. Clin. Lab. Invest. 1979, 39, 585 - 590.

12- GEDDES L.A., SADLER C.
The specific resistance of blood at body temperature.
Med. Biol. Engng 1973, 11, 336.

13- GOLLAN F., KIZAKEVICH P.N., Mc DERMOTT J.
Continuous electrode monitoring of systolic time intervals during exercise.
British heart J. 1978, 40, 1390 - 1396.

14- GOUGEROT L., MONZEIN P.
Etude critique des diverses méthodes de mesure des variations d'impédance des tissus profonds.
Am. Phys. Biol. et Med. 1970, 4, 159 - 199 et 1971, 5, 1 - 32

15- HARLEY A., GREENFIELD J.C.
Determination of cardiac output in man by means of impedance plethysmography
Aerospace Med. 1968, 39, 248 - 252.

16 - HILL D.W., LOWE H.J.
The use of electrical impedance technique for the monitoring of cardiac output and limb blood flow during anaesthesia.
Med. Biol. Engng. 1973, 534.

17 - HILL D.W., MERRIFIELD A.J.
Left ventricular ejection and the Heather index measured by non-invasive methods during postural changes in man.
Acta anaesth. Scand. 1976, 20, 213 - 220

18 - HORTON J.W.
Measurement of the impedance of the human body.
Gen. Radio Experimenter. 1936, 10 (9), 3.

19 - JUDY W.V., LANGLEY F.M., Mc COVEN K.D., STINNET D.M., BAKER L.E., JOHNSON P.C.
Comparative evaluation of the thoracic impedance and isotope dilution methods for measuring cardiac output.
Aerospace Med. 1969, 40, 532.

20 - KEIM H.J., WALLACE J.M., THURSTON H., CASE D.B., DRAYER J.I.M., LARAGH J.H.
Impedance cardiography for determination of stroke index.
J. Appl. Physiol. 1976, 41 (5), 797 - 799.

21 - KINNEN E.
Cardiac output from transthoracic impedance variations.
Ann. N.Y.Acad. Sci. 1970, 170, 745 - 756.

22 - KUBICEK W.G., KARNEGIS J.N., PATTERSON R.P., WITSOE D.A., MATTSON R.H.
Development and evaluation of an impedance cardiac output system.
Aerospace Med. 1966, 37, 1208 - 1212.

23 - LABABIDI Z., EHMLE D.A., DURNIN R.E., LEAVERTON P.E., LAVER R.M.
The first derivative thoracic impedance cardiogram.
Circulation, 19870, 41, 651 - 658.

24 - LABABIDI Z., EHMKE D.A., DURNIN R.E., LEAVERTON P.E., LAVER R.M.
Evaluation of impedance cardiac output in children.
Pediatrics 1971, 47, 870 - 879.

25 - Mc KENSIE R., WADHWA R.K., BEDGER R.C.
Non invasive measurement of cardiac output during laparoscopy
The J. Of Reproductive Med. 1980, 24 (6), 247 - 250.

26 - MITCHELL M.M., NEWBOWER R.S.
Intrathoracic electrical impedance measurements from an oesophageal probe.
Ann. J. Physiol. 1979, 236 (3), R 168 - R 174.

27 - NAGGAR C.Z., DOBNIK D.B., FLESSAS A.P., KRIPKE B.J., RYAN T.J.
Accuracy of the stroke index as determined by the transthoracic electrical impedance method.
Anaesthesiology 1975, 42 (2), 201 - 205.

28 - NYBOER S.D., BANGO S., BARNETT A., HALSEY R.M.
Electrical impedance plethysmography
J. Clin. Invest 1940, 19, 773

29 - RASMUSSEN J.P., SORENSEN B., KANN T.
Evaluation of impedance cardiography as a non invasive means of measuring systolic time intervals and cardiac output.
Acta anaesth. Scand. 1975, 19, 210 - 218.

30 - RASMUSSEN J.P., ERIKSEN J., ANDERSEN J.
Evaluation of impedance cardiography during anaesthesia in extremely these patients.
Acta anaesth. Scand, 1977, 21, 342 - 345.

31 - SECHER N.J., THOMSEN A., ARNSBO P.
Measurement of rapid changes in cardiac stroke volume. An evaluation of the impedance cardiography method.
Acta. anaesth. Scand. 1977, 21, 353.

32 - SIEGEL J.H., FABIAN M., LANKAV C., LEVINE M., COLE A., NAMMAD M.
Clinical and experimental use of thoracic impedance plethysmography in quantifying myocardial contractility.
Surgery, 1970, 67 (6), 907 - 917.

33 - SMITH J.J., BUSH J.E., WIEDMEIER V.T., TRISTANI F.E.
Application of impedance cardiography to study of postural stress.
J. Appl. Physiol. 1970, 29 (1), 133 - 137.

34 - VANFRAECHEM J.M.P.
Stroke volume and systolic time intercal adjustments during bicycle exercise.
J. Appl. Physiol. 1979, 46 (3), 588 - 592.

# CHAPTER 12

## SPECIAL TESTS

1. VALUE OF THE TILT TABLE IN THE EXPLORATION OF CIRCULATORY FUNCTION
   by J.Timbal

2. VALUE OF THE "LOWER BODY NEGATIVE PRESSURE" TEST IN AEROSPACE MEDICINE
   by B.Vettes and H.Vieillefond

3. METHODS AND MAJOR FINDINGS OF CARDIOVASCULAR EXPLORATION INVOLVING THE HUMAN CENTRIFUGE
   by B.Vettes and H.Vieillefond

# 1. VALUE OF THE TILT TABLE IN THE EXPLORATION OF CIRCULATORY FUNCTION

by J. Timbal*

Any change of position from the inclined to the upright position or vice versa results in important haemodynamic changes which result mainly from the rapid transfer of part of the total blood from one territory to another. The value of this type of manoeuvre in exploring circulatory system functions has long been known (BARACH et al 1931).
The simplest method is to request the subject to change position from lying on a bed to standing motionless upright . This method is easy to carry out but difficult to standardise. Furthermore the involvement of large muscles also affects circulatory conditions. The tilt table avoids these complications; it makes it possible to standardise observation conditions and to eliminate any muscular effect. If properly carried out, the method provides a passive orthostatic or antiorthostatic test.

In practice, it is the orthostatic tests which are most commonly used in both functional exploration during the selection or medical check up of aeronautical teams (SCANO 1974) and for more fundamental research. Antiorthostatic tests have been used particularly in the Soviet Union for the selection of cosmonauts.

In this article we will consider only the short term effects of passage from the horizontal to the vertical position because these are of particular importance in circulatory function exploration.

It would seem however that this tilt table test is not in universal routine use, probably because of doubts concerning the repeatability of determinations (SCHVARTZ 1968) despite attempts at standardisation (VOGT 1966), the difficulty of determining criteria of normality and the cost of the apparatus. Some authors prefer other tests such as the LBNP (HORDINSKY, 1980).

## I METHOD

The tilt table consists of a hard surface sufficiently big to allow patients to rest entirely on it without any effort to keep in position. The table must rotate easily about a horizontal axis and change from one position to another relatively quickly.

The subject's muscles must be relaxed. In order to obtain this relaxation in vertical or near-vertical positions, the subject must be supported by body belts and by a comfortable seat so as to avoid any pressure on the legs.

The position of the table is defined by the angle with the horizontal which serves as the reference. To test reactions related to the upright position, authors use angles of between + 45 and + 90 degrees. It would seem that maximum haemodynamic effects occur at an angle of + 70 degrees (TUCKMAN and SHILLINGFORD 1966).
This position has the advantage of being easier to maintain than the vertical position where the subject tends to tip forward. This is why this position is one of the most commonly used.

With respect to the duration of the tests, it would seem desirable to wait for about 20 minutes before changing position so as to ensure stable initial values. The new position must also be maintained for a similar period. In this way it is possible to detect any changes in the usual haemodynamic parameters.

The subjects must be monitored closely to avoid any loss of consciousness. In any subject presenting special risk, orthostatic tolerance should be tested using a smaller angle which may possibly subsequently be increased.

Factors which could affect circulatory reactions should be eliminated as far as possible. For this reason the subject should avoid a hot environment, heavy meals or severe physical exercise, all of which tend to reduce orthostatic tolerance, as well as a cold atmosphere, which in theory at least, may increase tolerance.

By way of example, antiorthostatic tests at -15 and -30 degrees for 6 minute periods with intervals in the horizontal position were used in the selection of some cosmonauts.

* Centre d'Etudes et de Recherches de Médecine Aérospatiale, 26 boulevard Victor, 75996 PARIS ARMEES France.

## 2 PRINCIPAL EFFECTS

The effects of the upright position on various physiological parameters have been the subject of many studies. The most commonly observed phenomena are as follows:

In some cases, syncope occurs and this is generally preceded by a feeling of malaise and palor which lead to the halting of the test. Syncope may occur immediately in subjects with a cardiovascular system incapable of adaptation and this reflects sluggishness of the sympathetic nervous system. More commonly it occurs after a delay of a few minutes. This is the phenomenon seen in bedridden subjects or those subjected to weightlessness for long periods. It is more difficult to explain this phenomenon and various fairly intricate mechanisms are probably involved. There is an initial failure of peripheral vaso-motricity, particularly of the veins which become incapable of adapting peripheral resistances (WARD et al (1966) and so allow the build up of blood in the lower parts of the body. This failure may occur rapidly and its consequences develop progressively up to the loss of consciousness or it may occur secondarily following vagal slowing in response to severe initial tachycardia. Subsequently there may be a failure of the angiotensin/renin system which is unable to cope with the situation.

The heart rate should normally rise as the table is tilted. The rapidity with which this occurs is a good sign of responsiveness of the sympathetic nervous system. However this tachycardia should remain moderate and not exceed an increase of 40% above resting values. A heart rate of above 100 is a negative feature. An excessive rise reflects insufficient adjustment of peripheral resistances and heralds syncope. However in certain cases syncope may be preceded by bradycardia. (WARD et al 1966).

Cardiac output is reduced during the orthostatic test. This has been known since 1944 (McMICHAEL and SHARPEY-SCHAFER 1944). This reduction which is a function of the angle of tilt is considerable and reaches about 65% in the vertical position (MATALON and FARHI, 1979; SEGEL et al, 1973). Since the heart rate is usually increased, this phenomenon is related to a fall in the systolic ejection volume (BEVEGARD 1960, SMITH et al 1970) .

The different phenomena result in a change in the systolic time intervals with the shortening of the left systolic ejection time (LVET) and an extension of the left pre-ejection period (LPEP), with a rise in the LPEP/LVET ratio. (SPODICK et al, 1971; STAFFOD et al, 1979).

Regional blood supply is of course affected. This has been confirmed for the cerebral blood flow which is reduced (WHITE and ROLD, 1948), the hepatic flow (CULBERTSON et al. 1951), and the flow in the forearm and hand (MENGESHA and BELL, 1979).

Interstitial and venous stasis in the lower parts of the body can be assessed by determining the overall increase in circumference and volume of the legs or by changes in tissue thickness (KIRSCH et al, 1980).

The blood pressure is of particular interest. During a change of position, the systolic arterial pressure tends to fall, but in the healthy subject this fall should be slight or rapidly overcome. Sometimes there may even be a very slight rise (ALLISON et al, 1970).

The diastolic arterial pressure rises and generally remains above resting values throughout the test.

In cases of poor tolerance there is a marked fall in the systolic pressure and a narrowing of the systolic/diastolic difference.

This simple test provides information useful not only for the assessment of orthostatic tolerance but also for the early detection of hypertension (FROHLICH et al, 1967).

The pressure in the pulmonary artery falls by about 30% during a tilt to + 60 degrees (LEWIS and CHRISTIANSON, 1978). Central venous pressure is also reduced.

With regard to respiration, the minute ventilation and the alveolar ventilation are increased by about 20% and the functional reserve volume by about 40%, in the vertical position (MATALON and FARHI, 1979).

Oxygen consumption increases only very slightly (RAHN and AHENT, 1955) so that the venous partial pressure of oxygen falls slightly in relation with the decrease in blood flow. On the other hand the venous partial pressure of carbon dioxide changes little, probably because of the opposed effects of the increase in alveolar ventilation and the decrease in cardiac output (MATALON and FARHI, 1979).

The effects of tilting from the vertical position to the horizontal position have rarely been investigated. It would seem that the phenomena detected are a reversal of those described above. This has been confirmed for the heart rate and the left systolic time (COLIN and TIMBAL 1980).

## 3 INTERPRETATION

The effects seen during the tilt table tests are related to changes in the effects of gravity on the body. Two morphological factors are involved:

- the anatomical arrangement of the large blood vessels, which generally follow the major axis of the body. Depending on whether the pull of gravity acts along this axis or perpendicularly to it, the static component of the intravascular pressure is changed.

- the low pressure distendability of the circulatory system. This system which contains about 85% of the total blood, includes major blood stream veins, the right heart, the pulmonary circulation and the left ventricle in diastole. The compliance of this system (3ml mm $Hg.kg^{-1}$) is much higher than that of the arterial system (0.015 ml.mm Hg. $kg^{-1}$).

It therefore easily changes shape as a result of changed pressure resulting from changes of position.

During a change to the upright position, the blood pressure rises in the lower part of the body particularly in the legs and blood accumulates in the distendable regions. The venous stasis produced corresponds to a liquid displacement of between 0.4 and 1 litre of blood mainly originating in the intra-thoracic vessels. This phenomenon results in reduced venous return and a reduction of the cardiac output sometimes described as "intravascular bleeding". In the absence of any compensating response, there would be a very severe fall in arterial pressure in the supracardiac territories,rapidly leading to a loss of consciousness during to impaired cerebral circulation.

The normal reaction involves various mechanisms which maintain an adequate perfusion of the various organs and of the brain in particular. These consist of very rapid adaptations of the circulatory flow and the peripheral resistances and, over a longer period, of the volume of the circulating blood.

Here we are concerned only with the rapid adaptations; the initial hypotension produced during the tilt has an immediate effect on the baroceptors. Via the autonomic nervous system, these receptors produce an acceleration of the heart rate and this tends to restore the cardiac output. They also trigger arterial and venous vaso-constriction which increases peripheral resistance and so the disturbances of arterial pressure are corrected although the efficiency of the system may vary from individual to individual.

Cutaneous and sub-cutaneous vaso-constriction may also occur in response to local sympathetic reflexes (HENRIKSEN 1981).

The involvement of the renin/angiotensin system occurs more gradually and the renin activity of the plasma rises from 20 to 50% of the resting baseline after 5 minutes and to 300% above the baseline after 60 minutes (SASSAR et al 1976). This activation is due to the reduced intrathoracic volume of blood which is detected by the stretch receptor in the atrial walls and to a reduction in the intra-renal arterial pressure stimulating the intra-renal stretch receptor and probably to a general activation of the adrenergic system. The angiotensin and particularly the angiotensin II released has both peripheral and central hypertensive effects which gradually take over from the initial response.

There is also a rise in the blood aldosterone level, but its effect on water and salt retention does not reach a detectable level for too long a period to be suitable for tilt table tests.

During a change from the vertical to the horizontal position, the stimulation of the circulatory system is reversed, the blood flows into the upper part of the body and the reservoir is filled. The blood pressure rises in the supracardiac territories. The baro- and stretch receptors trigger regulatory reactions, slowing of the heart rate and reduction of peripheral resistances. The inhibition of plasma renin activity is relatively slow since minimum values are reached only after about ten hours (CIER 1979).

Since the horizontal position can be maintained for long periods, it is possible to investigate more longterm adjustments which are intended to reduce the blood mass by inhibition of ADH-secretion and the stimulation of aldosterone secretion. However these are phenomena requiring longterm research and not involved in routine functional exploration.

## 4 CONCLUSION

Tilt table tests demonstrate the rapidity and efficacy of the cardiovascular responses to position changes, i.e. to changes in the effects of gravity. This test is therefore of great interest in aerospace medicine and may be included in selection and check up tests for the physical fitness of aircrew. However the way it can be included in the battery of routine tests, the standardisation of the protocol and of interpretation of the results remain to be defined more closely. This is why research into this question must continue.

BIBLIOGRAPHY


1 - ALLISON (R.D.), LEWIS (C.E.), RESEK (T.W.)
Vascular Dynamics. Impedance plethysmograph study during a standardized tilt table procedure.
Space Life Sciences. 1970. 2, 361-393.

2 - BARACH (J.H.), MARKS (W.L.)
Effect of change of posture without active muscular exertion on the arteriel and venous pressures.
Arch.Intern.Med., 1913, 11: 485-494.

3 - BEVEGARD (S.), HOLMGREN (I.), JONSSON (B.)
The effect of body position on the circulation at rest and during exercice, with special reference to the influence on the stroke volume.
Acta Physiol.Scan. 1960,49 : 279-298.

4 - CIER (J.P)
La physiologie du système rénine angiotensine.
J.Physiol. (PARIS) 75, 179-193, 1979.

5 - COLIN (J.), TIMBAL (J.)
Modifications des temps systoliques provoqués par le passage en absence de pesanteur.
Rev.Med.Aéro. 1980 ( sous presse )

6 - CULBERTON (J.W.), WILKINS (R.W.), INTGELFINGER (J.), BRADLEY (S.E.)
The effect of the upright posture upon hepatic blood flow in the normotensive and hypertensive subjects.
J.Clin.Invest. 1951, 30 : 305-311.

7 - FROLHICH (E.D.), TARAZI (R.C.), ULRYCH (M.), DUSTAN (H.P.) , PAGE (I.H.)
Tilt test for investigating a neural component in hypertension
Circulation. 1967, 36, : 387-393.

8 - HENRIKSEN (O.)
Cardiovascular reflexes during urpight position in " Human cardiovascular adaptation to zéro gravity".
E.S.A. ; SP. 1033 Janaury 1981 : 10-12.

9 - HORDINSKY (J.R.) , GEBHARDT (U.) , BORGER (H.J.), BIRK (J.)
Orthostatic Tolerance Testing : comparaison of LBNP and HUT methods.
Z.Flugwiss. Weltraum fosch . 1980, 4, 194-200.

10 - KIRSCH (K.A.), MERKE (J.), HINGHOFER-SZALKAY (H.), BARNKOW (M.), WICKE (H.J.)
A new miniature pletysmograph to measure volume changes in small circumscribed tissue areas.
Pflügers Arch. 1980, 383 : 189-194.

11 - LEWIS (M.L.); CHRISTIANSON (L.C.)
Behavior of the human pulmonary circulation during head-up tilt.
J.Appl.Physiol. 1978, 45 :249-254.

12 - MATALON (S.V.), FARHI (L.E.).
Cardiopulmonary readjustements in passive tilt.
J.Appl.Physiol. 1979, 47 : 503-507.

13 - Mc MICHAEL (J.), SHARPEY-SCHAFER (E.R.)
Cardiac output in man by a direct Fick method. Effects of posture on venous pressure change, atropine and adrenaline.
Brit.Heart J. 1944, 6 : 33-40

14 - MEUNGESHA (Y.A.), BELL (G.H.)
Forearm and finger blood flow responses to passive body tilts.
J.Appl.Physiol.1979, 46 . 288-292

15 - PATTERSON(J.L.Jr), CANNON (J.L.)
Postural changes in the cerebral circulation studied by continuous oximetric and pressure recording techniques.
J.Clin.Invest.1971, 30 : 664-665.

16 - RAHN (H.), AMENT (R.)
The effects of posture upon gas exchange and alveolar gas exchanges.
In : Studies in respiratory physiology 1955 : 327-336 (WADC, Tech.rep. 55-357 )

17 - SASSARD (J.), VINCENT (M.), ANNAT (G.), BIZOLLON (C.A.)
Akinetic study of plamsa renin and aldosterone during changes of posture in man.
J.Clin Endocrinol.Metab. ; 1976, 42, 20-27.

18 - SCANO (A.)
Survey of current cardiovascular and respiratory examination method in medical selection and control of aircrew.
AGARD - AG. 196, 1974, 6-9.

19 - SEGEL (N.), DOUGHERTY (R.), SACHNER (M.A.)
Effects of tilting on pulmonary capillary blood flow in normal man.
J.Appl.Physiol.1973, 35 : 244-249.

20 - SHVARTZ (E.)
Reliability of quantitative tilt table data.
Aerospace Med. 1968, 39 : 1094-1097.

21 - SMITH (J.J.), BUSH (J.E.), WIEDMEIER (V.T.), TRISTANI (F.E.).
Application of impedance cardiography to study of postural stress.
J.Appl.Physiol. 1970, 29, (1), 133-137.

22 - SPODICK (D.H.), MEYER (H.), St PIERRE (J.R.)
Effect of upright tilt on the phases of the cardiac cycle in normal sugjects.
Cardiovasc.Res. 1971, 5 : 210-214.

23 - STAFFORD (R.W.), HARRIS (W.D.), WEISSLER (A.M.)
Left ventricular systolic time intervals as indices of postural circulatory stress in man.
Circulation 1970, 51 : 485-492.

24 - TUCKMAN (J.), SHILLINGFORD (J.)
Effect of different degress of tilt on cardiac output, heart rate and blood pressure in normal man.
Brit. Heart.J. 1966, 28 : 32-39.

25 - VOGT (F.B.)
An objective approach to the analysis of tilt table date .
Aerospace Med. 1966, 37 : 1195-1204.

26 - WARD (R.J.) , DANZINGER (F.), BONICA (J.J.), ALLEN (G.D.), TOLAS (A.G.)
Cardiovascular effects of change of posture
Aerospace Med 1966, 37 : 257-259

27 - WHITE (H.L.), ROLD (D.)
Effect of exercice and of some other influences on the renal circulation in man.
An.J.Physiol.1948, 152 : 505-516.

# 2. VALUE OF THE "LOWER BODY NEGATIVE PRESSURE" TEST IN AEROSPACE MEDICINE

by B Vettes* and H. Vieillefond **

## 1 INTRODUCTION

Weightlessness poses three main problems to space medicine. The changes of distribution of blood and vestibular volumes resulting in space sickness .

The study of the physiopathological effects of weightlessness is not easy, since these occur when the human body escapes from the attraction of the earth. It is therefore necessary to use simulation methods to explore the functioning of the various physiological systems involved.

With respect to the effect of weightlessness on cardiovascular function, it soon became obvious that the physiopathological effects may be related to a new distribution of the blood volumes and that the so-called orthostatic tests would provide interesting information. At present there are two types of test able to produce similar blood volume distributions to those detected during prolonged space flights and during the return to earth. One type of test involves changes of position of the whole body; these are functional explorations carried out on tilt tables or during very prolonged bedrest. The other type of test produces pressure differences surrounding the upper and lower parts of the body and so causes the mass of blood to be transferred into the territories surrounded by the lowest pressure. This is the test known as the "lower body negative pressure" test or LBNP. It may be of interest to note that French authors use these initials as there is no recognised French term.

## 2 TECHNICAL ASPECTS AND PROCEDURE

The test requires the use of an air-tight container into which the lower part of the subject's body is placed up to the level of the antero-superior iliac crests.

To the best of our knowledge, there is no caisson available on the market for the purposes of this test and each laboratory or unit of functional exploration has to prepare their own.

The force of the container may vary greatly and is of little importance. The authors use an Afcodur cylinder which is 500 mm in diameter and 1500 mm in length i.e. with a value of 295 dm3. This can be made of hardboard, metal or plastic, the essential feature being that the structure is not deformed by the changes in pressure applied.

There are no special problems attached to the production of relatively small reductions in pressure. A system of vacuum pumps easily provides depressions of about 100 h Pa if the caisson is not too large.

The most difficult problem would seem to be that of the sealing around the body which must be thorough and which must adapt itself to the shape of the subject being tested. The most satisfactory solution would appear to be that used in the Physiology, Biophysics and Medicine Department of the University of Kentucky Medical Centre (16) which uses an iris-like structure. However it is not easy to introduce the subject into the container or to get him out again.

The assembly used by NASA at the Houston Manned Spacecraft Centre (13) overcomes most of the obvious drawbacks. For reasons of economy, the authors have preferred to use a Neoprene tube which the subject wears like a belt and which fits onto an Afcodur cylinder to which it is laced. If a whole population is to be covered, two or three different lengths of tubing should be provided.

In the Yuri Gagarin cosmonaut training centre, Soviet researchers use an inflatable sausage, which provides a very good waist-seal when inflated but does produce some abdominal pain.

## 3 EXPERIMENTAL PROTOCOLS

There is no standard test protocol and the literature includes many methods differing with respect to the duration and extent of the pressure depression applied.

For the selection of cosmonaut candidates, the Soviets use the following protocol:
After a rest period of 15 minutes the following pressure reductions are applied:

* Research specialist in the Service de Santé des Armées;
** Professeur Agrégé at EASSA-CERMA
L.A.M.A.S. Centre d'Essais en Vol
91220 - Bretigny sur Orge France

33 h Pa for two minutes
47 h Pa for three minutes
60 h Pa for five minutes
67 h Pa for five minutes

followed by a return to normal pressure.

This protocol is simple, and rapid and produces sufficient change in the circulating blood masses to assess cardiovascular function.

This protocol was also used in the selection of French spacionaut candidates in the Saliout-Soyouz project of 1982.

In the United States where more studies have been undertaken, the protocols vary from author to author with respect both to the extent of pressure duration and the time for which it is applied. However, overall, one can divide the protocols into two groups. One group are all fairly similar to the Soviet protocol and involve stages of 5 minutes at -40, then at -53 and finally at -67 h Pa (3); the other group have longer periods of exposure and sometimes greater pressure reductions, for instance LOEPPKY (6) uses three successive stages of 10 minutes at -27, -53 and -80 h Pa.

Other protocols involve a single exposure, which may be fairly lengthy, to reduced pressure.

WOLTHUIS (14) subjected his subjects to reductions of -53 h Pa applied for 15 minutes; STEVENS et al (2) had an exposure period of 20 minutes.

FASOLA et al (2) investigated several protocols by changing the pressure reduction applied to the lower body over a 30 minute period.

WOLTHUIS et al (15) carried out a valuable study comparing the cardiovascular response of subjects under a protocol involving a single pressure reduction and under a protocol involving progressive stages of reduction. The first protocol involved a reduction of -53 h Pa applied for 15 minutes, and the second involved three successive stages of 5 minutes at -27, -40, and -53 h Pa. There was no significant difference between the results (heart rate, leg volume, systolic ejection volume) obtained during the final minutes of the two tests. In other words, it would seem that the extent of the depression would seem to be a more significant physiological stimulus that the time for which this depression is applied. The authors also report that the test involving progressive stages has the advantage of providing better information concerning the development of vascular changes. The use of a simple prolonged reduction of pressure would also seem to produce more frequent vascular collapse and loss of consciousness. At present it would seem that constant level LBNP tests are being abandoned in favour of tests involving successive increments.

## 4 RESULTS

The effects of the LBNP test have frequently been studied and can be divided into two groups which we will consider separately. The first group contains the cardiovascular effects and the second the respiratory effects. It is obvious that this distinction is totally arbitrary, and it is evident that depression of intrathoracic inspiration affects the return of venous blood.

### 4.1 Cardiovascular effects

From the cardiovascular point of view, the depression applied to the lower body during the test has the major effect of displacing part of the blood mass towards the intracardiac territories.

This displacement of the blood is accompanied by a series of physiological changes, the most important of which is probably the fall in central venous pressure. This effect results in a reduction of the systolic ejection volume and hence of the cardiac output in accordance with STARLING's law and may result in a fall of arterial pressure as ROWELL (10) and ROWELL et al (11) have shown.

Of course the regulatory mechanisms are involved and maintain the arterial pressure sufficiently to ensure perfusion of the noble organs. These mechanisms are of two types. The first are rapidly called into play and produce reflex orthosympathetic activation from the sino-carotid and aortic baroceptors. This in turn produces an increase in the heart rate, the contractility of the myocardium and of the peripheral vascular resistances. The second group are more long term in effect and involve renal and hypothalomo pituitary endocrine adjustments, in response to signals from the stretch receptor of the right atrium. These produce water retention and hence maintenance of blood volume (SHIMIZU et al (12).

As well as the fall of central venous pressure, the accumulation of blood in the venous reservoir system of the legs involves a very considerable increase in the transmural pressure which results in a net plasma flow into the extravascular spaces.

The change in volume of the legs is extremely rapid and depends on the pressure reduction applied to the lower body.

MUSGRAVE et al (7), using a water plethysmograph system, demonstrated that legs submitted to a pressure reduction of -53 h Pa show an increase in volume of 2.9% after one minute of exposure, 3.4% after three minutes and 3.6% after five minutes. According to these authors the level of filtration of plasma across the vein wall is of the order of 0.03 ml/mn per 100 ml of tissue and hence very similar to the data published by DRURY and JONES (1) in 1927.

Very recently POIRIER (18) during the selection of French cosmonauts carried out at the Centre National d'Etudes Spatiales, and using an electrical impedance plethysmograph, was able to measure changes in the volume of the calf during pressure reductions of as much as 67 h Pa. The mean increase in volume of the leg varied from subject to subject between 1.2 and 5.8 % with a group mean of 2.6%. These figures exactly match those of LOEPPKY et al (6) which were obtained with pressure reductions of up to 80 h Pa.

For many authors and particularly for the specialists at the NASA Johnson Space Center (5), the physiological parameter most sensitive to the changes produced by LBNP is beyond doubt the heart rate.

All the studies published to date report a considerable increase in the heart rate during the test.

In a comparative study of the cardiovascular results obtained in three different orthostatic tests following prolonged bedrest to simulate weightlessness, HYATT et al (3) were able to show that the LBNP was frequently the test which produced the greatest change in heart rate.

In POIRIER's study already mentioned (8), a mean increase of 30% in the heart rate was obtained.

4.2 Respiratory effects

The main effect of the LBNP on the ventilatory mechanism is a shift of the thoraco-pulmonary compliance plot towards the left by about 15% of the reserve functional capacity . This is fairly similar to the changes described by RAHN et al (9) during a change from the prone to the sitting position. LOEPPKY et al (6) report and increase in pulmonary ventilation essentially related to an increase of the flow volume.

The gas exchanges of course altered because of the reduced central blood volume. The diffusion capacity of the lung, assessed from the DiL/CO) is reduced by 17% after 6 minutes of LBNP at -53 h Pa (ZECHMAN et al (17) . in a similar field, LOEPPKY et al (6) detected a fall of 20% in the pulmonary capillary transfer of oxygen during the first minute of an LBNP test at -26 h Pa accompanied by a fall in the oxygen content of venous blood .

5 APPLICATION OF THE LBNP TEST IN AEROSPACE MEDICINE

The lower body negative pressure test is of two-fold interest in aerospace medicine. Firstly, it provides an excellent method for investigation of the cardiovascular and respiratory changes associated with weightlessness and secondly it provides a method of preventing these problems during flight .

STEVENS et al (13) have shown that the daily use of the LBNP during a period of one month of total bedrest is very effective in preventing the loss of plasma, reducing the increase in heart rate and maintaining the cardiac index at a more satisfactory level during the LBNP. It is therefore not surprising that use of the LBNP has been extended to the training of astronauts and to the prevention of the severe orthostatic syndromes which occur after a return from a mission.

In 1976, JOHNSON et al (5) reported the American experience following the skylab flight (3) and the usefulness of LBNP seemed obvious to these authors. Currently all orbital stations are equipped with a caisson suitable for carrying out this test.

However, aeronautical medicine can also benefit from the lower body negative pressure test not only as a clinical orthostatic test but especially as a means of investigating cardiovascular adaptation capacity to the positive longitudinal accelerations known as + C .

The physiopathological disturbances produced by + Gz accelerations are of vascular origin and the mechanism by which they occur is fairly similar to that underlying LBNP. It is of interest to note that weightlessness reduces the tolerance of accelerations. (JACOBSEN et al (4)).

The use of the centrifuge to investigate acceleration tolerance remains a costly test which is difficult to operate and and in some circumstances it can be complemented by the LBNP test.

BIBLIOGRAPHY


**1 - DRURY A.N. and JONES N.W.**
**Observations upon the rate at wich oedema forms when the veins of the human limbs are congested.**
**Heart 1927 - 14 - 55 -70**

**2 - FASOLA A.F., MARTZ B.L.**
**Peripheral Venous Renin Activity during 70° tilt and lower Body Negative Pressure**
**Aerospace Med. 1972 43 (7) 713-715**

**3 - HYATT K.H. JACOBSON L.B., SCHNEIDER V.C.**
**Comparison of 70° tilt, LBNP and passive standing as measures of orthostatic tolerance.**
**Aviat. Space Environ. Med. 1975 46 (6) 801-808**

**4 - JACOBSON L.B., HYATT K.H., SANDLER H.**
**Effects of simulated weightlessness on responses of untrained men to + Gz accélerations.**
**J. Appl. Physiol. 1974 36 (6) 745-752.**

**5 - JOHNSON R.L., NICOGOSSIAN A.E., BERGMAN S.A. HOFFLER G.W.**
**Lower Body Negative Pressure : the second manned skylab mission**
**Aviat. Space Environ. Med. 1976 47 (4) 347-353**

**6 - LOEPPKY J.A., VENTERS M.D., LUFT U.C.**
**Blood volume and cardiorespiratory responses to lower Body Negative Pressure**
**Aviat. Space Environ. Med. 1978 49 ( 11) 1297-1307**

7 - MUSGRAVE F.S., ZECHMAN F.W., MAINS R.C.
Changes in total leg volume during Lower Body negative pressure
Aerospace Med. 1969 40 602-606

8 - POIRIER J.L.
Les tests d'orthostatisme lors de la sélection des cosmonautes
Med. Aéro. et Spat. Med. sub. Hyp. 1981 ( à paraitre )

9 - RAHN H., OTIS A.B., CHADWICK L.E., FENN W.O.
The pressure volume diagram of the thorax and lung
Am. J. Physiol 1974 146 - 161 - 178

10 - ROWELL L.B.
Regulation of splanchnic blood flow in man.
Physiologist. 1973 16 127-142

11 - ROWELL L.B., BLACKMON J.R. WYSS C.
Importance of the splanchnic vascular bed in human blood pressure régulation.
J. Appl. Physiol. 1972 32 213-220

12 - SHIMIZU M., GEISTA D.N., SANDLER H.
Cardiovascular Regulatory Response to lower body negative pressure following blood volume loss
Aviat. Space Environ. Med. 1979 50 (1) 24-33

13 - STEVENS P.M., MILLER P.B., GILBERT C.A. , LYNCH T.N., JOHNSON R.L., LAMB L.E.
Influence of long term Lower Body Negative Presure on the circulatory function of man during prolonged bed rest.
Aerospace Med. 1966 37 (4) 357-367

14- WOLTHUIS R.A., HOFFLER G.W., JOHNSON R.L.
Lower Body Negative pressure as an assay technique for orthostatic tolerance I the individual response to a constant level ( - 40 mmHg) of LBNP.
Aerospace Med. 1970 41 ( 1) 29-35

15 - WOLTHUIS R.A., HOFFLER G.W., JOHNSON R.L.
Lower Body Negative Presure as an assay technique for orthostâtic tolerance II a comparison of the individual response to incrimental us constant levels of LBNP.
Aerospace Med. 1970 41 (4) 419-424

16 - WOLTHUIS R.A., HOFFLER G.W., BAKER J.T.
Improved Waist Seal Design for Use With Lower Body Negative Presure (LBNP) devices.
Aerospace Med. 1971 42 (4) 461-462

17 - ZECHMAN F.M., MUSGRAVE F.S., MAINS R.C., COHN J.E.
Respiratory mechanics and pulmonary diffusing capacity with Lower Negative Presure
J. Appl. Physiol. 1967 22 (2) 247-250

## 3. METHODS AND MAJOR FINDINGS OF CARDIOVASCULAR EXPLORATION INVOLVING THE HUMAN CENTRIFUGE

by B. Vettes* and H. Vieillefond**

Cardiovascular function is particularly sensitive to the prolonged accelerations encountered in aeronautics.

During + Gz accelerations, the forces of inertia are directed towards the legs. They tend to produce an accumulation of blood in the lower regions, i.e. especially in the splanchnic veins and the veins of the legs which dilate considerably. As the accelerations increase, there is a fairly rapid accumulation and within a few seconds the venous return to the heart is not sufficient to provide satisfactory cerebral irrigation. Furthermore the increase in the weight of the blood column above the heart produces excessively low arterial pressure in the terminal arteries of the retina and encephalon even though the cerebral flow of the major trunks is maintained by a syphon effect between the right heart and the left heart.

The body calls correcting mechanisms into play, particularly a rise in the heart rate, vasoconstriction and increased force of cardiac contraction. This haemodynamic tolerance is a function not only of the degree of acceleration but also of the duration and of the suddenness with which it is applied. This tolerance may be increased by various physiological manoeuvres (manoeuvres M1, M2 or L1) and the use of respiration under increased pressure and anti-g equipment.

During - Gz accelerations, the forces of inertia are directed towards the head, and the arterial and venous pressures above the heart rise as soon as the - Gz acceleration begins. The fall in heart rate accompanied by reduced systolic output and cerebral arterial pressure is due to the sino-carotid reflex triggered by carotid hypertension.

During transversal accelerations, ± Gz and ± Gy, the forces of inertia are directed perpendicularly to the axis of the major blood vessels. This is why the circulation is much less severely affected and tolerance much better.

However, experience has shown that transverse accelerations do produce notable cardiovascular reactions. It has been possible for over forty years to reproduce ± Gz, ± Gx and ± Gy accelerations in the seated or reclining subject using the human centrifuge. The centrifuge remains an excellent means of investigating the efficacy of protective devices, particularly anti-g clothing. Research has concerned both anti-g trousers and the anti-g valve. The purpose of the research is to improve the comfort of the clothing (BURTON and KRUTZ 1975; DAVIES 1976, SHAFFSTALL 1978) of producing uniform pressure within the clothing (BURTON et al, 1973; KRUTZ et al 1974) of ensuring improved efficacy of the anti-g valve by a pre-inflation technique (SUCHNER and DOUGHERTY 1973, VETTES et al 1979) or by changing the conditions of inflation (THOMPSON et al, 1978 a and b).

In general the following parameters are recorded:

- heart rate
- electrocardiogram
- arterial pressure
- heart output, local flow
- visual field.

However, generally the methods of determination are invasive involving the trauma of catheterisation and considerably hindering the subject under test. It is of great interest to have available non-invasive and simple methods. This is the purpose of the present article.

### 1 - Heart rate

This can be measured by phonocardiography, with the phonocardiograph firmly attached to the thorax of the subject by an elastic strap (VETTES et al, 1979). However, during the centrifugal movement, the instrument is severely affected by the surrounding noise. This is why the heart rate is often calculated from the electrocardiographic recording. At the BRETIGNY Laboratory of Aerospace Medicine, the heart rate is calculated from three cycles and continuously displayed by a digital computer.

Since only a very approximate value is obtained, it is preferable to calculate the value from ten cardiac cycles on the electrocardiogram.

During + Gz acceleration, the heart rate increases in function of the acceleration up to + 7 Gz and may reach 150 to 180 beats per minute; above this acceleration further increase is slight (PARKHURST et al, 1972; SHUBROOKS, 1972; SHUBROOKS and LEVERETT, 1973; LEVERETT et al, 1973; BURTON et al, 1974). In lower accelerations of 4-5 Gz, the anti-g trouser is able to afford some protection, limiting the tachycardia whilst retaining the adaptive function of the tachycardia in restricting the fall in cardiac output (VETTES et al, 1979).

This tachycardia has three components:

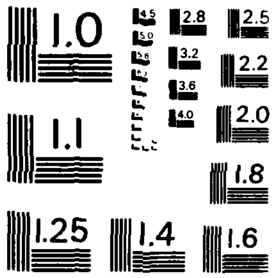
- an emotional factor
- physiological manoeuvres (M1, L1) intended to improve tolerance

* Research specialist at the Service de Santé des Armées,
** Professeur Agrégé at the EASSA - CERMA
L.A.M.A.S. Centre d'Essais en Vol 91220 - Brétigny sur Orge, France

AD A138 965 NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE(U) ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT NEUILLY.. R CARRE ET AL. 3/3

UNCLASSIFIED DEC 83 AGARD AG-277(E) F/G 6/5 NL

END
DATE FILMED
4 84
DTIC




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

- the Gz accelerations themselves.

However SHUBROOKS and LEVERETT (1973) reported a reduced heart rate in a subject exposed to + 7.5 Gz. The heart rate of the subject changed from 160 to 80 beats per minute between the 18th and the 30th second was reported by KIRKLAND and KENNEALY in 1976 and by GILLINGHAM and CRUMP (20). The interpretation of this phenomenon is not clear and there may have been some pathological cause.

During - Gz acceleration, sinus bradycardia is detected (VETTES and POIRIER 1978) . The heart rate may fall to 38 beats per minute and may even be followed by cardiac arrest (BONDURANT and WILLIAM 1958).

During Gx transverse accelerations, the heart rate increases but to a lesser extent in the case of moderate accelerations; for accelerations of 8, 10 or 12 g, higher values may be reached (VETTES and AUFFRET 1980) and the heart rate may reach 160 or even more beats per minutes in the prone subject (BONDURANT et al 1958).

2 - The electrocardiogram

This is performed routinely in all experiments as a safety precaution. However, there are some technical difficulties in picking up, amplifying and transmitting the signal. Tolerance of high levels of acceleration requires the M1 and L1 manoeuvres which involve contraction of the abdominal muscles and the limbs which results in considerable myogram parasiting of the electrocardiogram. This is why the usual precordial and peripheral leads are replaced by electrodes at sites such as those used in medicine of sport.

At the BRETIGNY Laboratoire de Médecine Aérospatiale, the ECG is obtained in two ways :

In the first method, three electrodes are attached to the previously scoured skin of the subject, two under the armpits and one in the dorsal region (VETTES et al, 1979).

In the second method, four electrodes are attached to the skin, one in each of the supraspinous fossa (right and left), and the other opposite the triangle of Jean-Louis PETIT.

These arrangements provide the three standard peripheral derivations (D1, D2 and D3). The second arrangement minimises baseline disturbances due to the myogram and respiratory changes. This method provides an excellent signal/sound ratio. It also leaves the thorax completely available for the placing of the plethysmograph electrode and for the phonocardiographic detector (VETTES and AUFFRET 1980).

After amplification, the electrical signals picked up by the electrodes are transmitted via revolving compacts towards the terminal recorders and displayed on a cathode oscilloscope equipped with a memory, the screen of which is placed in front of the supervising physician .

Rhythm disturbances, and ventricular extrasystoles frequently occur during and after exposure to + Gz accelerations, particularly if these are prolonged (SHUBROOKS and LEVERETT, 1973). VETTES et al, 1979, recorded the onset of superior nodal extrasystoles and sometimes bigeminous ventricular extrasystoles at + Gz. According to LEGUAY et al, 1978, the frequency of extrasystoles during extreme accelerations may precipitate or intensify mitral prolapse.

Other abnormal features may appear, such as MOBITZ type 2 sino-ventricular dissociation, sino-atrial block or atrial extrasystole.

Changes in the shape of the tracing have been reported. These usually consist of the flattening or even inversion of the T-wave (COHEN et al, 1969 and BURTON et al 1974 b). Sometimes the ST segment may be depressed (BURTON et al., 1974 b). However, because of the muscular artefacts resulting from the exertion of the M1 manoeuvre, these changes are difficult to interpret. The vectocardiogram has frequently been investigated and has the advantage of visualising electrical vectors in three dimensions: the frontal, sagittal and transverse planes. None of the authors have reported any pathological signs (BONDURANT et al., 1958; COHEN et al, 1970).

According to LAUGHLIN et al, 1980, during high accelerations (7 Gz), the QRS complex undergoes posterior rotation in the sagittal plane and anti-clockwise rotation in the transverse plane. These disturbances are probably more closely related to changes in the position of the heart in the thorax than to cardiac failure. However, GILLINGHAM and CRUMP, 1976; and WILL et al, 1978, reported transient changes in the angle of the T loop, suggesting disturbed repolarisation.

During -Gz accelerations, KINNEALY et al, 1976, detected the onset of a slow and irregular junctional rhythm which persisted for some time after the end of the test.

Transverse accelerations may also produce electrocardiography disturbances (ROGGE et al, 1969 and VETTES, 1980). VETTES and AUFFRET, 1980, suggested the presence of an intermittent sino-atrial block with escape beats at + 8 Gx, as well as extrasystoles at + 8 Gx. One subject presented severe bradycardia and changed base-line rhythm following the halting of transverse accelerations. Basic atrial activity disappeared and there was slow junctional escape. However, there were small features in the tracing just before and just after the ventricular complex which suggest the possibility of retrograde or dissociated P-waves. The main features therefore are a depression of sinus activity accompanied by junctional rhythm and possibly some depression of atrio-ventricular activity. These phenomena are part of the short-term vagal rebound phenomenon and have no particularly negative significance from the cardiovascular point of view.

3 - Arterial pressure

The arterial pressure in the eye is usually assessed from the pressure in the radial artery determined by a catheter, with the detector placed at the same level as the eye by suitable positioning of the wrist and forearm (LEVERETT et al, 1973; SHUBROOKS, 1973; SHUBROOKS and LEVERETT, 1973; KRUTZ et al, 1973; GILLINGHAM et al, 1979 and 1978).

However this is an invasive method which is not free from drawbacks, since the catheterisation of the radial artery may produce pain in the forearm and arm as well as in the thorax (intercostal spaces) or even a loss of consciousness (GILLINGHAM and CRUMP, 1976).

This is why the BRETIGNY Laboratoire de Médecine Aérospatiale has spared no effort to develop an accurate non-invasive and indirect method of determining the arterial pressure.

In 1958, CABANON and SERIS developed an instrument for determining the arterial pressure based on the principle of pulse detection.

The systolic arterial pressure is determined by means of an arm band placed on the left arm of the subject. Alternating inflation and deflation of the band are controlled by an electrovalve.

A manocontact limits the maximum pressure of inflation of the armband to 300 mb i.e. 22.5 cm Hg. The pressure inside the armband is determined by a mutual inductance manometer.

A capacitance pulse detector (infraton) attached between two fingers transforms changes in pressure due to the blood flow in the artery into changes of potential. These changes are amplified in the container of the centrifuge, particularly under low impedance to a level of about 1 volt and are then transmitted to the recording assembly.

The left forearm of the subject rests in an adjustable groove which keeps the arm fitted with the armband at the level of the clavicle .

The systolic and diastolic arterial pressures are now determined by means of a pneumatic armband which is inflated and deflated by an electromechanical system controlled directly from the control desk. Recordings are made of the pressure within the armband and the appearance or disappearance of Korotkoff sounds detected by a highly sensitive microphone placed over the humeral artery at the end of the elbow.

A method involving auscultation in this fashion inevitably results in errors in the systolic and diastolic pressure determinations by means of the Korotkoff sounds.

The sounds recorded result from the beats of the heart. There is a variable latent period between the time when the pressure within the armband reaches the true arterial pressure and the onset of the Korotkoff sound. This delay may be as great as a whole cardiac cycle. The error is therefore greatest in subjects with a slow heart rate and with excessively rapid deflation of the armband. In practice, for a subject with a heart rate of about 60 to 70 beats per minute and with a deflation rate such that the armband is completely deflated within about 25 seconds, this error should not exceed one third of a cm of Hg for maximal pressure.

A method of this type was used by PELLIGRA et al, 1973. In the Soviet Union, the Korotkoff sounds are determined from the inflation pressure of the armband .

However, during the revolutions of the centrifuge, the microphone also picks up the surrounding noise and vibrations and it becomes very difficult to interpret the recordings. For this reason a differential determination is carried out between the main pouch of the armband and a small secondary pouch over the brachial artery and kept at a pressure similar to that of the large pouch by means of a leakage resistance. A $\pm$ 5 mb differential capsule between the two pouches detects the oscillations due to arterial beats.

Determination of the arterial pressure in the eye involving M1-L1 respiratory manoeuvres, respiration in increased pressure and the wearing of anti-g clothing has been carried out particularly by LEVERETT et al, 1973; SHUBROOKS, 1973; SHUBROOKS and LEVERETT 1973 .

The anti-g trouser of itself tends to raise the arterial pressure in the eye even at low accelerations (CABANON and SERIS, 1959).

SHUBROOKS (1973) demonstrated the beneficial effect of the M1 or L1 manoeuvre and of respiration under increased pressure on arterial pressure.

For VETTES et al, 1980, an increase in both systolic and diastolic arterial pressure is normal in subjects with good acceleration tolerance. During both Gx and Gz accelerations, if the pressure remains low or collapses, there is a rapid loss of vision and sometimes a total loss of consciousness.

Any sudden increase in pressure, especially if accompanied by a narrowing of the differential is also a sign of intolerance (VETTES et al, 1979).

4 - Venous pressure:

This was studied by LEVERETT et al (1973), (BURTON et al, 1974), at both central and peripheral levels but requires the use of invasive methods. The central venous pressure is determined by means of a catheter introduced into the medium cubital vein and pushed into the superior vena cava of the right atrium. The intra-thoracic pressure, measured by means of an oesophagial probe, serves as a reference.

The peripheral venous pressure at the ankle is determined by means of a catheter introduced into a surface vein of the ankle.

Methods of this type are not used in France, and only the determination of the blood flow in the limbs by means of the electrical plethysmograph can be used to determine venous accumulation (VILIAMS).

5 - Cardiac output:

Most of the methods for determining cardiac output are invasive methods requiring complete catheterisation. In 1960, LINDBERY used a method of cardio-green dilution. Other authors have attempted an estimation based on the investigation of changes in X-ray opacity of the heart (LEVERETT et al. 1973) or gamma ray opacity (KOPPENHAGEN et al, 1978).

GRAYBOYS and MICHAELSON (1976) evaluated the systolic ejection volume from the systolic time intervals determined using a cardiogram and phonocardiogram.

For many years LAMAS have used an electrical plethysmographic method which is able to determine changes in cardiac output or more exactly changes in the systolic ejection volume, DEMANGE, 1970.

The principle is simple: when a body segment is crossed by a high frequency electrical current, the variations of volume related to circulatory changes occurring in the segment, result in changes in electrical impedance. A current with high frequency (100 KHz) and low voltage is injected between two electrodes placed on the skin, one electrode is placed at the base of the neck (carotids), and the other a hand's breadth below the left nipple (the lower precordial region) or beneath the rib cage.

The current flows between the two electrodes along the conductors offering the least resistance to its passage (aorta, major vessels of the trunk).

Changes in impedance, measured between two cutaneous electrodes placed either on the sternal manubrium, above the ascending aorta, or on the thorax, above the thoracic vessels, correspond to a change in volume of the arterial segment lying between the electrodes which is itself proportional to the systolic ejection volume.

The graphical interpretation suggested by KUBICEK (extensions throughout the cardiac systole of the steepest slope at the beginning of the systolic wave) and determination of the systolic time interval from the phonocardiogram or from the ECG by means of the usual shape, make it possible to determine if not the exact systolic ejection volume, at least a value representative of it and changing in proportion to it.

Given the heart rate it is also possible to deduce both the aortic and thoracic blood flow.

The equation required is as follows:

$$\Delta V = \frac{\Delta R \times p \times L2}{Ro\ (Ro + \Delta R)}$$

where

$\Delta V$ = change in volume (ml)
$\Delta R$ = change in electrical impedance (ohms/cm ) (calculated from the graph)
p = resistivity of the circulating blood (ohms/cm ) (mean value = 153)
L = distance between the detection electrodes (cm)
Ro = baseline resistance between the electrodes (ohms)
R and Ro are determined by means of a resistance placed in series with the ejection electrodes and with an electrical potential opposite to that detected by the two detection electrodes.

At present this apparatus is undergoing some modifications, particularly concerning the calibration, which is carried out within the apparatus itself by means of a known resistance. There is also the possibility of an automatic or manual return to the base-line.

This apparatus has four commutable channels and can be used to follow displacement of the aorta during acceleration by means of a multiple array of electrodes.

Correlations with invasive determinations in man (cardio-green), carried out by DEMANGE et al, 1973, have shown that the absolute figures for the cardiac output are fairly equivalent except for very short subjects (with a short aorta).

However, this method is quite suitable for use in evaluation changes of output as a percentage of the resting value.

By a similar method, ZOUBAVINE et al, 1972, analysed the reactions of the cardiovascular system during experiments in the human centrifuge.

DEMANGE, 1970, showed that during + 3 Gz longitudinal accelerations over a prolonged period (15 to 20 minutes), subjects without anti-g protection presented malaise with falls in the systolic ejection volume, arterial pressure and changes in heart rate (bradycardia or tachycardia).

However, the wearing of anti-g trousers produced excellent tolerance with an increase in the systolic ejection volume, cardiac output and arterial pressure and reduced tachycardia.

The same observation was made by VETTES et al, 1979 and 1980.

During the Gz acceleration, the systolic ejection volume is considerably reduced (-40 to -50%) and despite the tachycardia, the cardiac output falls by 25 to 30%.

Subjects presenting visual disturbances (grey or black mist), also present low arterial pressure and a considerable reduction of the systolic ejection volume (65%) and of the cardiac output and one subject even lost consciousness completely.

The fall in thoracic volume on exposure to 10 Gx acceleration is of the order of 45% and a fall in output of the order of 13% . Here too a very low arterial pressure 9/4.5 is accompanied by a collapsing thoracic volume (fall of 75% with reduction of the visual field).

6 - Local blood flow:

It should be noted that it is important to determine local blood flow, particularly cerebral flow, during accelerations and this may provide a fairly good reflection of the retinal circulation.

PELLIGRA et al, 1973, KRUTZ et al. 1975 determined the flow in the superficial temporal artery by means of a Doppler electromagnetic flowmeter and demonstrated the relationship between the reduction of cerebral circulation, the fall in arterial pressure within the eye and visual criteria (black mist).

Other authors, such as WOOD et al, 1963, used a photoelectric apparatus placed on the lobe of the ear to detectchanges in opacity of the ear (blood content) during longitudinal Gz accelerations.

DUANE (1954) and LEVERETT and NEWSON (1971) applied a method of retinal photography involving a fluorescent substance to show that the black mist, a subjective phenomenon, did correspond with the halting of retinal circulation.

DEMANGE and DEMON (1963) explored the cerebral circulation by means of a two-electrode rheoplethysmograph. In the two-electrode method, the part of the body under examination (skull) is inserted by means of two electrodes, into a branch of a WIEN bridge supplied with alternating current with a frequency of 150,000 Hz. A calibration assembly placed in series makes it possible to assess changes in the rheographic curve. The mean equilibrium of the bridge is obtained by adjusting the variable rheostats and capacitances which are placed in series on another branch.

The disequilibrium potential created by changing the impedance of the deep tissues is recorded at the exit from the impedance detector and relayed through two amplifiers. A continuous amplifier gives the base line and an alternate amplifier the rheogram. These two parameters are recorded on two channels of the graphical recorder.

The two electrodes stuck on either side of the skull record changes in volume of the large cerebral vessels. They are held tightly in place against the skin by means of an elastic strap which also prevents any changes in capacitance and virtually interrupts the circulation of blood in the scalp beneath the electrodes.

The tangent to the curve in the descending portion of the systole is used in interpreting the graph. The distance between this tangent and the isoelectric line at the onset of systole is equivalent to a change of resistance $\Delta$ R, which is nearer to what actually happens (NYBOER).

DEMANGE (1967) was able to follow the fall in cerebral flow (or at least of an index of this flow) during longitudinal Gz accelerations. The appearance of the grey or black mist was reflected in a severe reduction of the cerebral arterial pulse.

The 4-electrode electrical plethysmograph can also be used.

7 - The visual field:

The assessment of the visual criteria is an excellent way of assessing the haemodynamic tolerance of a subject to acceleration. A loss of peripheral or central vision indicates retinal circulatory failure heralding cerebral failure. Many authors have suggested visual criteria of tolerance. The various criteria suggested include the loss of peripheral vision (PLL: Peripheral light loss) and the loss of central vision (CLL: Central light loss), or 50% loss of central vision (CLD: Central light dim) (PARKHURST et al, 1972; SHUBROOK, 1973; COBURN, 1975; HILL 1978). The technical assemblies used may be very simple involving Only 3 lamps.(one central red lamp and 2 peripheral green lamps ) or highly complex (PELLIGRA et al 1973 and GILLINGHAM and MACNAUGHTON 1977).

At LAMAS the visual test explored peripheral vision along a meridian. 16 small white lights are placed every 10 degrees on a semi-circular ramp placed on a horizontal plane which passes through the eyes of the subject. The two outermost lights, if they are visible, correspond to a visual field of 180°.

From the medical surveillance post, a control box provides random lighting of the outermost light to the right and left. The subject must maintain central vision and put out the lights by means of a push button. The time taken to put them out is converted into numerical form and included inthe print-out. Failure to put out a light is considered as a reduction of the visual field by 20° and the lighting pattern moves on to the following combination. The arrangement of lights is reproduced on the control desk in front of the physician.

This system is able to explore the visual field and also to assess the time taken to respond (the reaction time) to a luminous signal (the mean time taken to switch on the light is about one second).

Under both Gz and Gx accelerations, the reduction of visual field is related to marked hypotension and a collapse in the thoracic or systolic ejection volume and also to subjective effects: grey or black mist (VETTES and AUFFRET 1980).

8 - Conclusions:

Sustained Gz and Gx accelerations definitely affect cardiovascular function and consequently use of the human centrifuge must always be accompanied by close cardiovascular monitoring by the investigator. The various non-invasive methods of functional investigation have the advantage of being simple to carry out, and of being suitable for prolonged and repeated use .

## BIBLIOGRAPHY

1 - BONDURANT S., and WILLIAM A.F.
The spatial vectocardiogram during acceleration
Aviat. Med. 1958, 29 758-762

2 - BURTON R.R. et KRUTZ R.M.
G tolerance and protection with anti-g suit concepts
Aerosp. Med. 1975, 46 , 119-124

3 - BURTON R.R., MAC KENZIE, M.F. et SPLITTER, G.A.
Heart pathology associated with high sustained + Gz
Aerosp. Med. Ass. Preprint, 1974 (b) 40-41

4 - BURTON R.R., MAC KENZIE, M.F.
Cardiac pathology associated with high sustained + Gz
I - Subendocardial hemorrhage.
Aerosp. Med. 1976 , 47 - 711-717

5 - BURTON R.R., PARKHURST, M.J. et LEVERETT Jr. S.D.
+ Gz protection afforded by standard and pre-acceleration inflations of the bladder and capstan type G suits.
Aerosp. Med. 1973, 44 - 488-494.

6 - BURTON R.R. LEVERETT, S.D. et MICHAELSON E.D.
Man at high sustained + Gz acceleration. A review
Aerosp. Med. 1974, 45 - 10 1115-1136

7 - CABANON A. et SERIS H.
Evaluation of human tolerance to accelerations of centrifuge by measuring arterial blood pressure.
C.E.V. / C.R.E. 1958 n° 649. 5 p.

8 - CABANON A. et SERIES H.
Action du vêtement anti-g sur la tension artérielle pour des accélérations de longue durée et de faible intensité.
C.E.V. / C.R.E. 1959 n° 435. 5 p.

9 - COBURN K.R.
Physiological end points in acceleration research
Aerosp. Med. 1970, 41 5-11

10 - COHEN,G.H. et BROWN W.K.
Changes in E.C.G. contour during prolonged + Gz acceleration
Aerosp. Med. 1969 (b), 40 874-879

11 - COHEN,G.H. et BROWN, W.K.
Electrocardiographic changes during positive acceleration.
J. Appl. Physiol. 1969 (a) 27 , 858-863

12 - COHEN,G.H., BROWN, W.K., STOWE, D.W. et FITZ Patrick, E.L. et THREATT, D.
Analysis of the Frank orthogonal vectocardiogram during gravitational stress.
Aerosp. Med. 1970 41, 8

13 - DAVIES, J.M.
A compar.ison of recent advances in british anti-g suit design.
AGARD R 642 - 1976 - 71-73

14 - DEMANGE, J. et DEMON
Etude des effets de l'hypercapnie et des accélérations sur les variations d'impédance céphalique ( rhéographie).
CEV.CRE Avril 1967 - 38p.

15 - DEMANGE, J.
Sélection de l'équipe de France de Bobsleigh ( Jeux Olympiques).
Etudes du comportement circulatoire cérébral sous accélérations longitudinales.
C.E.V. R.E. n° 1 de déc. 1967. 6 p.

16 - DEMANGE, J.
Débit cardiaque ( par pléthysmographie électrique) chez l'homme soumis à des accélérations de longue durée + 3 Gz.
Rev. Med. Aéro et Spa. 1970 9, 33. 11-13

17 - DEMANGE, J., PERNOD J., HAGUENAUER et J. COLIN
Validation d'une méthode rhéopléthysmographique de mesure de débit cardiaque utilisée dans l'étude des agressions aérospatiales.
Rev. Méd. Aéro et Spa. 1973. 12 , 46. 282-283

18 - DOWELL, R.T. et STONE H.L.
Specificity of heart biochemical changes resulting from + Gz acceleration.
ASMA Preprints 1978 - 79-80

19 - DUANE, T.D.
Observations on the fundus oculi during blackout.
Arch. Ophtalmol. 1954. 51 . 343-345

20 - GILLINGHAM, K.K. et CRUMP, P.P.
Changes in clinical cardiologic measurements associated with higli + Gz stress.
Aerosp. Med. 1976 47 , 726-733

21 - GILLINGHAM, K.K., FREEMAN, J.J. et MACNEE, R.C.
Transfer functions for eye level blood pressure during + Gz stress.
Aerosp. Med. 1977 - 48 1026-1034

22 - GILLINGHAM, K.K. et MAC NAUGHTON, G.B.
Visual field contraction during G stress at 13°, 45° and 65° seatback angles.
Aerosp. Med. 1977 - 48 91-96

23 - GILLINGHAM, K.K. et MAC NOE, R.C.
Mathematical modeline of criterial oxygen saturation and eye-blood level pressure during plus Gz stress.
AGARD CP 253.

24 - GRAYBOYS et MICHAELSON, E.D.
Systolic time intervals during plus Gz acceleration.
J. Appl. Physiol. 1976 41 52-56

25 - HULL, D.H., WOLTHUIS, R.A. GILLINGHAM K.K. et TRIEBWASSER J.H.
Relaxed + Gz tolerance in healthy men, effect of age.
J. Appl. Physiol. 1978

26 - KENNEALY, J.A., KIRKLAND, J.S. et SNEIDER, R.E.
Bradycardia induced by negative acceleration.
Aerosp. Med. 1976, 47 5.

27 - KIRKLAND, J.S. et KENNEALY, J.A.
Prolonged visual less and bradycardia following deceleration from + G Gz acceleration : a case report.
Aerospace Med. 1976, 47 310-311.

28 - KOPPENHAGEN, K., VOGT, L., WERRIG, H.G. HARDIEK, J. et FRANKE, J.
Feasibility of measuring cardiac output under increased + Gz using a scintillation camera.
26th International Congress of Aerospace Medicine - Londres 4-2 sept. 78.

29 - KRUTZ, R.W., LEVERETT, S.D., BURTON, R.R. et BURNS.
+ Gz protective methods for use in advanced fighter - attack aircraft.
AGARD CP 154, 1974, C6, 1-7

30 - KRUTZ, R.W., ROSITANO, L. Jr. S.A. et MANCINI, R.E.
Comparison of techniques for measuring + Gz tolerance in man.
J. Appl. Physiol. 1973, 38 , 1143-1145.

31 - KUBICEK, W.G.
Development and evaluation for impedence cardiac output system.
Aerospace Med. 1966, 37 , 12 , 1208-1212.

32 - LAUGHLIN, M.H., WHINNERY, J.E., COSGROVE, D.J., FITZPATRICK, E.L. et KEISER, H.N.
Vectocardiography results of human exposures to + 3 Gz, + 5 Gz and + 7 Gz.
Report SAM TR 80-31 octobre 1980.

33 - LAUGHLIN, M.H., WITT, W.M. et WHITTAKER
Regional cerebral blood flow in concious miniature swine during high sustained + Gz acceleration stress.
Aviat. Space Environ. Med. 1979, 50 , 11, 1129-1133.

34 - LEGUAY, C., DRONIOU, J., SEIGNEURIC, DURET. J. et PERNOD J.
Prolapsus mitral et acceleration.
Med. Aero et spa. Med. Suba et Hyperbare 1978 - 17 - 67 - 229-235.

35 - LEVERETT, S.D. et BURTON, R.R.
The use of a fixed base simulator as a training device for high sustained or ACM ( Air Combat Manoeuvering ) + Gz stress
AGARD CP. 189 - 1976 - A7.

36 - LEVERETT, S.D. et NEWSOM, W.A.
Photographic observations of the human fundus oculi during + Gz black out on the USAF school of Aerospace Medicine Centrifuge.
19th Congress of the International Astronautical Federation - New-York October 13-19, 1968. 1-2.

37 - LEVERETT, S.D. RUSSEL, R.B., CROSSLEY, R.J. MICHNELON, E.D. et SHUBROOKS, S.J.
Physiologic response to high sustained + Gz acceleration.
USAF-SAM TR - 73-21 1973 pp. 71.

38 - LINDBERG, E.F., SUTTERER, W.F., MARSHALL, H.W.
Measurement of cardiac output during heardward acceleration using the dye - dilution technique.
Aerosp. Med. 1960 31, 817-834.

39 - MAC KENZIE, M.F., BURTON, R.R. et BUTCHER.
Cardiac pathology associated with high sustained + Gz.
II - Stress cardiomyopathy.
Aviat. Space Environ. Med. 1976, 47 , 718-725.

40 - NYBOER, J.
Electrical impedance plethysmography.
Thomas Publ. 1959 - Springfield U.S.A.

41 - PARKHUST, M.J., LEVERETT, S.D. et SHUBROOKS, S.J.
Human tolerance to high sustained + Gz acceleration.
Aerospace Med. 1972 - 43 , 708-712.

42 - PELLIGRA, R. , SANDLER, H., ROSITANO, S., SHRESINGLAND, K. et MANCINI, R.
Advances techniques for monitoring human tolerance to + Gz accelerations.
Rev. Med. Aero et Spa. 1973, 12 , 46, 301-304.

43 - RAMACCI, C.A. et MEINERI, G.
Utilisation of human centrifuge for training military pilots in the execution of protective straining maneuvers.
AGARD. CP 189 1976 A7.

44 - ROGGE, J.D., MEYER, J.F. et BROWN, W.K.
Comparison of the incidence of cardiac arrhytmias during + Gx acceleration treadmill exercice and tilt table testing.
Aerospace Med. 1969, 40 , 1-5.

45 - SACKNER. M.A. et.DOUGHERTY R.
Anti-G suit inflation on cardiac output of seated subject.
Rev. Med. Aero 1973 12 264-266.

46 - SEM-JACOBSEN, C.W.
Stress response and stress tolerance in fighter pilots during 6 G manoeuvres.
AGARD CP. n° 189 1976 A.8.

47 - SHAFFOTALL, R.M.
Physiological evaluation of the + Gz protection by a small bladder volume anti-G suit.
ASMA Preprint 1978 - 48-50

48 - SHUBROOKS, S.J.
Changes in cardiac rythm during sustained high levels of positive ( + Gz) acceleration.
Aerospace Med. 1972 43 , 11, 1200-1206

49 - SHUBROOKS, S.J.
Positive pressure breathing as a protective technique during Gz acceleration.
J. Appl. Physiol. 1973 , 35 , 294-298

50 - SHUBROOKS, J.J. et LEVERETT, S.D.
Effect of valsalva manoeuvre on tolerance to + Gz acceleration.
J. Appl. Physiol. 1973 , 34 , 460-466

51 - THOMPSON, R.W., MECKER, L.J., WILSON G.L. , KNIEGER, A.G. et LOVE, P.E.
Engineering test and evaluation during high G.
Volume I : data evaluation techniques and equipment test.
SAM. TR. 78-10 , 1978 a, pp. 71.

52 - THOMPSON, R.W., MEEKER, L.J., WILSON, G.L. KRUEGER, A.G. et LOVE, P.E.
Engineering test and evaluation during high G.
Volume II : anti-G valves
SAM. TR. 78-11, 1978 b, pp. 81

53 - VETTES, B.
Aspects cardiovasculaires des accélérations de forte intensité et de longue durée
Rapport CEV/LAMAS ( à paraître ).

54 - VETTES, B. et AUFFRET, R.
Intérêt de la centrifugeuse dans la sélection des cosmonautes.
Congrès. Int. Med. Aéro. MONTREAL 1980

55 - VETTES, B. LEGUAY, G. , VIEILLEFOND, H., SEIGNEURIC, A. et AUFFRET, R.
Accélérations et aptitude des pilotes d'avion de combat.
Méd. Aéro et Spa. Med. Sub. Hyp. (sous presse).

56 - VETTES, B. et POIRIER, J.L.
Réactions cardiaques au cours des essais de tenue du harnais du yankee escape system sous accélérations - Gz
Med. Aéro et Spa. Med. Suba et Hyperbare 1978 17 67, 245-250.

57 - VETTES, B., POIRIER, J.L., DEHAYES, J. , BEZAMAT, G.
Etude de l'amélioration de la protection des équipages contre les effets des accélérations.
C.E.V. R.E. n° 18 1979, 23 p.

58 - VETTES, B., VIEILLEFOND, H., AUFFRET, R.
Cardiovascular responses of man exposed to plus Gz accelerations in a centrifuge.
Aviat. Space and Environ. Med. 1980, 51 , 4 , 375-378.

59 - VILIAMS, I.F.
Effect of periodic exposures to head-to-feet acceleration in a short-arm centrifuge on cardio vascular responses.
Kosmitcheskaia biologia i Aviakosmitcheskaia Meditsina
1980 - 14 - 4 - 48-51.

60 - WHINNERY, J.E. et GONDEK, M.R.
Medical evaluation of G sensitive aircrewmen
Aviat. Space Environ. Med. 1978, 49, 1009-1013.

61 - WHINNERY, J.E., LAUGHLIN, M.H. et HICKMAN, J.R.
Concurrent loss of consciousness and sino-atrial block during + Gz stress.
Aviat. Space Environ. Med. 1979, 50, 6, 635-638

62 - WOOD, E.H., LINDBERY, E.L., CODE, C.F. et BALDES, E.J.
Effect of partial immersion in water on responses of healthy men tb heardward acceleration.
J. Appl. Physiol. 1963, 18 , 6, 1171-1179.

63 - ZOUBAVINE, V.A., LETROKA, L.S., NIROCHNIKOV, Y.S.
Use of multi-channel rhéography during physiological investigations in a centrifuge.
Kosmitcheskaïa biologica i Mettitsina 1972, 6 , 5 , 75-79

| REPORT DOCUMENTATION PAGE | | | |
|---|---|---|---|
| 1. Recipient's Reference | 2. Originator's Reference<br>AGARD-AG-277(E) | 3. Further Reference<br>ISBN 92-835-1464-5 | 4. Security Classification of Document<br>UNCLASSIFIED |
| 5. Originator | Advisory Group for Aerospace Research and Development<br>North Atlantic Treaty Organization<br>7 rue Ancelle, 92200 Neuilly sur Seine, France | | |
| 6. Title | NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE | | |
| 7. Presented at | | | |
| 8. Author(s)/Editor(s)<br>Various | | | 9. Date<br>December 1983 |
| 10. Author's/Editor's Address<br>Various | | | 11. Pages<br>208 |
| 12. Distribution Statement | This document is circulated in accordance with the AGARD policies and regulations shown on the back cover of all AGARD publications. | | |
| 13. Keywords/Descriptors | Aerospace medicine<br>Cardio-vascular system | Cardiography<br>Biomedical determinations | |

14. Abstract


Non invasive cardiological methods, because of the very fact of their being non-invasive and easily repeated, are of increasing importance in the expert examination of flying personnel and in research in aeronautical and space medicine.

The authors describe these new methods and show what the aeronautical expert can hope for from them. There are three categories of method:

(1) The usual expert examination tests: standard electrocardiogram and cardiac radiography

(2) Complementary tests enabling the expert to check the organic and functional integrity of the cardiovascular system:
- exercise test
- Holter 24-hour monitoring of the electrocardiogram
- echocardiography
- ultrasonic examination
- isotopic exploration

(3) Special tests
- cardiac rheoplethysmograph
- balistocardiography
- tilt table
- LBNP test
- centrifuge test


This document is published by the AGARD Aerospace Medical Panel.

| AGARDograph No.277(E) | AGARD-AG-277(E) |
|---|---|
| Advisory Group for Aerospace Research and Development, NATO<br>NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE<br>Published December 1983<br>208 pages<br><br>Non invasive cardiological methods, because of the very fact of their being non-invasive and easily repeated, are of increasing importance in the expert examination of flying personnel and in research in aeronautical and space medicine.<br><br>The authors describe these new methods and show what the aeronautical expert can hope for from them. There are three categories of method:<br><br>P.T.O | Aerospace medicine<br>Cardio-vascular system<br>Cardiography<br>Biomedical determinations |


| AGARDograph No.277(E) | AGARD-AG-277(E) |
|---|---|
| Advisory Group for Aerospace Research and Development, NATO<br>NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE<br>Published December 1983<br>208 pages<br><br>Non invasive cardiological methods, because of the very fact of their being non-invasive and easily repeated, are of increasing importance in the expert examination of flying personnel and in research in aeronautical and space medicine.<br><br>The authors describe these new methods and show what the aeronautical expert can hope for from them. There are three categories of method:<br><br>P.T.O | Aerospace medicine<br>Cardio-vascular system<br>Cardiography<br>Biomedical determinations |

| AGARDograph No.277(E) | AGARD-AG-277(E) |
|---|---|
| Advisory Group for Aerospace Research and Development, NATO<br>NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE<br>Published December 1983<br>208 pages<br><br>Non invasive cardiological methods, because of the very fact of their being non-invasive and easily repeated, are of increasing importance in the expert examination of flying personnel and in research in aeronautical and space medicine.<br><br>The authors describe these new methods and show what the aeronautical expert can hope for from them. There are three categories of method:<br><br>P.T.O | Aerospace medicine<br>Cardio-vascular system<br>Cardiography<br>Biomedical determinations |

| AGARDograph No.277(E) | AGARD-AG-277(E) |
|---|---|
| Advisory Group for Aerospace Research and Development, NATO<br>NON-INVASIVE METHODS OF CARDIOVASCULAR EXPLORATION IN AEROSPACE MEDICINE<br>Published December 1983<br>208 pages<br><br>Non invasive cardiological methods, because of the very fact of their being non-invasive and easily repeated, are of increasing importance in the expert examination of flying personnel and in research in aeronautical and space medicine.<br><br>The authors describe these new methods and show what the aeronautical expert can hope for from them. There are three categories of method:<br><br>P.T.O | Aerospace medicine<br>Cardio-vascular system<br>Cardiography<br>Biomedical determinations |

(1) The usual expert examination tests: standard electrocardiogram and cardiac radiography

(2) Complementary tests enabling the expert to check the organic and functional integrity of the cardiovascular system:

- exercise test
- Holter 24-hour monitoring of the electrocardiogram
- echocardiography
- ultrasonic examination
- isotropic exploration

(3) Special tests

- cardiac rheoplethysmograph
- balistocardiography
- tilt table
- LBNP test
- centrifuge test

This document is published by the AGARD Aerospace Medical Panel.

ISBN 92-835-1464-5

(1) The usual expert examination : standard electrocardiogram and cardiac radiography

(2) Complementary tests enabling xpert to check the organic and functional integrity of the cardiovascular s

- exercise test
- Holter 24-hour monitoring of rocardiogram
- echocardiography
- ultrasonic examination
- isotropic exploration

(3) Special tests

- cardiac rheoplethysmograph
- balistocardiography
- tilt table
- LBNP test
- centrifuge test

This document is published by the AGARD Aerospace Medical Panel.

ISBN 92-835-1464-5

(1) The usual expert examination tests: standard electrocardiogram and cardiac radiography

(2) Complementary tests enabling the expert to check the organic and functional integrity of the cardiovascular system.

- exercise test
- Holter 24-hour monitoring of the electrocardiogram
- echocardiography
- ultrasonic examination
- isotropic exploration

(3) Special tests

- cardiac rheoplethysmograph
- balistocardiography
- tilt table
- LBNP test
- centrifuge test

This document is published by the AGARD Aerospace Medical Panel.

ISBN 92-835-1464-5

(1) The usual expert examination tests: standard electrocardiogram and cardiac radiography

(2) Complementary tests enabling the expert to check the organic and functional integrity of the cardiovascular system

- exercise test
- Holter 24-hour monitoring of the electrocardiogram
- echocardiography
- ultrasonic examination
- isotropic exploration

(3) Special tests

- cardiac rheoplethysmograph
- balistocardiography
- tilt table
- LBNP test
- centrifuge test

This document is published by the AGARD Aerospace Medical Panel.

ISBN 92-835-1464-5

END

DATE
FILMED

4 - 84

DTIC